Background Report 1

Effects of Cloud Seeding on Rainfall in the West Coast

Hydro Tasmania and West Coast Council   April 2008

SGS
Economics & Planning

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&

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Executive summary

Regional rainfall regime

Overall rainfall in Queenstown is high, around 2500 mm per annum. Moreover, the natural variability of rainfall is very high. Seasonal rainfall typically varies by plus or minus 23% from the average in any year. From May to October more than half of all days receive rainfall over 1 mm. Monthly rainfall varies even more with August rainfall usually varying 46% below or above the monthly average. Extreme rainfall seasons or months vary even more. Of all recorded extreme high rainfall months, none have occurred within the current operational phase of cloud seeding and half occurred prior to 1948.

The high natural variability makes it extremely difficult to discern cloud seeding effects. Long term experiments are required to produce conclusive evidence. "Even in the best experiments, it has taken more than a hundred seeded days to detect with any confidence, a 10% increase due to seeding", (Bigg, E.K. & Turton, E., 1988). These experiments need to meet stringent design criteria in order to deliver useful data.

Long term rainfall data do not reveal any obvious trend in annual precipitation for Queenstown, but there seems to be a shift in seasonal patterns. Autumn appears to have become drier over the past 100 years while late winter and spring have been experiencing increasing rainfall. At the annual level these two movements largely compensate each other. Such apparent trends occur against a background of large inter-decadal variability. The reference rain gauges, Bureau of Meteorology's (BoM) high quality gauges at Cape Grim, City of Melbourne Bay (CMB), Osterley and Yolla, all have significantly lower rainfall than Queenstown. Rainfall variability at these sites is high, just as in Queenstown. Rainfall trends at CMB seem to correlate reasonably with Queenstown while the remaining three sites show quite different trends. Rainfall patterns vary strongly from one place to the other.

At the local scale, rainfall statistics for Queenstown, Strahan and Rosebery also vary strongly between each other.

Measures of cloudseeding effectiveness

The review of experiments and findings shows that clear evidence of the effectiveness of cloud seeding is often elusive. Of all of the areas in the world, evidence for effectiveness is strongest in Western Tasmania.

Cloud seeding experiments show seeding is most effective when clouds have a high super cooled liquid water content. The premise is that cloud seeding can improve the efficiency of precipitation by the appropriate introduction of artificial ice nuclei into clouds deficient in naturally occurring ice nuclei as evidenced by a high supercooled liquid water content (LWC). The relationship between supercooled LWC and precipitation is not straightforward but results from Stage II suggest that Tasmanian cloud seeding operations are effective in increasing rain on an already rainy day.

Cloud seeding is potentially effective in regions where clouds frequently undergo orographic uplift; i.e. airflow over mountainous areas. The most suitable clouds are stratus clouds in a maritime airstream with cloud tops between -10°C and -12°C. These circumstances occur often on the Tasmanian West Coast.

Impacts of cloud seeding in Western Tasmania

Collating various studies on cloud seeding in Tasmania, the conclusion is that cloud seeding is effective and that precipitation is enhanced by up to 8% per 'seeded' month in the target areas.

The current operational phase of cloud seeding commenced in September 1998 and continues to present. Cloud seeding operations are undertaken from April to November. There are fewer flights during April and November (approximately 2 seeding events per month), while July through to October are the most intensely seeded months (approximately 5.5 events per month). While Hydro Tasmania conducts an average of four seeding operations per month, the number of flights is roughly twice as high because suitability of cloud conditions for seeding can only be assessed during flights.

The most common target area is Gordon, which is not near any of the townships of the West Coast. Other areas that are targeted frequently during seeding flights are Upper Derwent and Upper Pieman. Rosebery is located west of Upper Pieman and Tullah within it. King catchment – which is targeted the least of all areas – is next to Queenstown. Strahan and Zeehan are both further away from the catchment areas and are not areas where clouds may undergo orographic uplift.

Further randomised trials could better evaluate the impacts of cloud seeding, but the benefits would have to be demonstrable given the opportunity cost of not seeding. Targeting could be refined by using more sophisticated modelling, potentially reducing unintended effects.

The scientific review reveals that one scientist has undertaken analysis of seeding experiments to try to assess persistence effects and has concluded that there is some evidence of persistence effects from seeding. Most other scientists believe there is no evidence or that at best any evidence is inconclusive. In particular, there is no credible identified mechanism by which persistence could occur as seeding crystals would be blown across the State and out to sea within hours to at most a day or so. However, even if persistent effects last up to several days, the experimental design means they would be included in the overall estimated impact. Only longer term persistence effects would be missed by the analytical methods used.

Five of 31 extreme rainfall events in Rosebery coincided with cloud seeding operations but there is no proof of a causal relationship. These were not the most extreme events for Rosebery. Seeding operations are undertaken if there is a good chance of rainfall anyway increasing the likelihood of such coincidence.

There is no scientific evidence that shows cloud seeding operations deprive the eastern half of Tasmania from rainfall. International research so far has not been able to establish significant evidence of rain deprivation in downwind areas. Rainfall on the West Coast results from weather conditions that are not comparable to the conditions producing rain in the Midlands and the East Coast, being produced by separate weather systems.

There is no evidence of adverse environmental and health effects of the seeding agent silver iodide.

For tourism, it is useful to know what effect cloud seeding has on the number of rainy days whereas in regard to flood impacts the rainfall amounts would be most significant.

The magnitude of the effects of cloud seeding is still regarded as uncertain by most scientists. However, there are some clear indications of the range within which these effects lie. There is some evidence that suggests some unintended seeding occurs outside the targeted areas. Rosebery and Tullah are most prone to these effects.

The **maximum** effect of cloud seeding in these townships would be up to 8% increase in monthly rainfall **for seeded months**. There should be no effect on the number of rainy days.

Seeding occurred on 5 days during which extreme rainfall was recorded in Rosebery over a nine year period. Seeding is expected to contribute to **at most** 1 extreme rainfall event every two years (on average) in Tullah and Rosebery. Queenstown may experience such an event once in approximately 10 years time. Consequently, Strahan could potentially be affected by a combination of flooding through the King River and high tide **at most** once a decade too.

At the minimum, the effects of cloud seeding are estimated to be negligible in townships outside target areas. Scientific evidence so far does not produce any **substantial** evidence of unintended seeding outside the targeted areas. The evidence provided is not more than suggestive. If there are no outside target area effects then there should be no effects of cloud seeding in Queenstown, Rosebery, Zeehan and Strahan. Tullah is located within the Upper Pieman target area and in terms of minimum effects, is expected to be affected by cloud seeding. Rainfall effects in Tullah at a minimum are estimated to be a 4% increase in monthly rainfall **for seeded months**.

Rainfall in Zeehan is not likely to be affected by cloud seeding at all, being well upwind from any target area and not mountainous. The township is not known to be prone to flooding as a consequence of excessive rainfall. Therefore, our 'best estimate' is that cloud seeding does not affect Zeehan at all.

1 Introduction

1.1 Background

As early as the 1920s the South African Weather Service attempted hygroscopic seeding from a biplane. The earliest generally recognised scientific attempt at glaciogenic[1] cloud seeding was by Schaefer (1946) and Vonnegut (1947) in USA. Soon after, Commonwealth Scientific Industrial Research Organisation (CSIRO) started its field experiments in Australia (Kraus and Squires, 1947). More experiments followed in many parts of the world. The results of these experiments often proved to be inconclusive. A confounding issue in trying to assess the effects of cloud seeding on rainfall is the natural variability of rainfall. "Even in the best experiments, it has taken more than a hundred seeded days to detect with any confidence, a ten percent increase due to seeding" (Bigg & Turton, 1988). Consequently, it is even harder to establish statistical significant evidence for smaller effects.

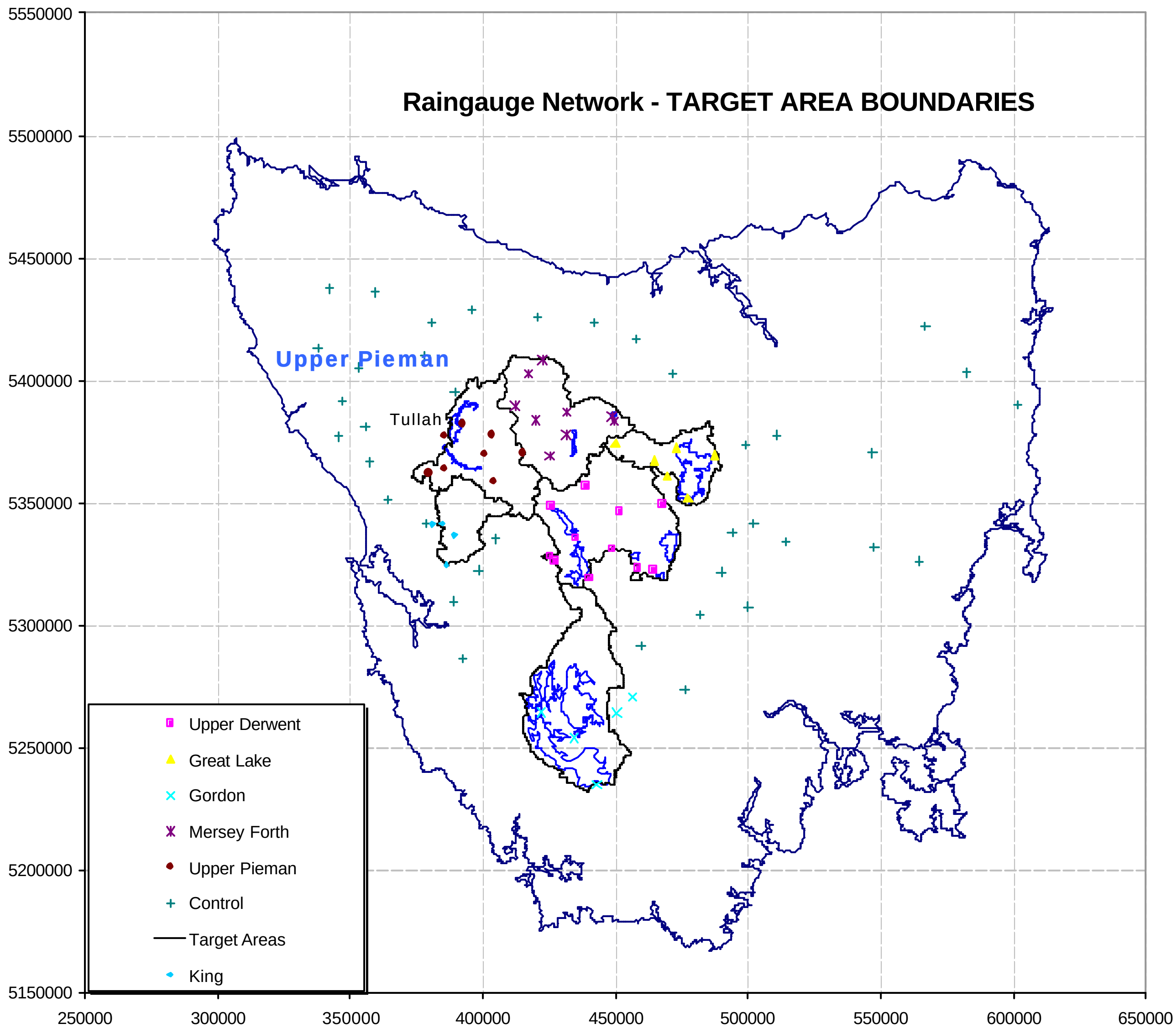
Hydro Tasmania in close cooperation with CSIRO conducted its first experiment from 1964 to 1971. A second experiment took place between 1979 and 1983. Both these experiments used silver iodide (AgI) released from a plane as seeding agent. Then, from 1992 to 1994 a third experiment was implemented and this time dry ice was used as seeding agent. The two Tasmanian trials using AgI as the seeding agent returned strong evidence that cloud seeding is in fact enhancing rainfall in the targeted areas. The third trial in which dry ice was used as the seeding agent produced inconclusive results. Hydro Tasmania, on the basis of these results, continued to use AgI as the seeding agent.

In addition to these experiments, operational cloud seeding has been applied from 1988-91 as a drought relief program over an enlarged target area. In 1973, 1994-95 and 2000 seeding took place in agricultural areas in the Tasmanian Midlands and East Coast.

From 1998 onwards, Hydro Tasmania engaged in an operational program that continues to this day. The current phase aims to enhance the storage levels in Hydro Tasmania's dams based on the catchments shown in Figure 1. Just recently, Hydro Tasmania announced an expansion of its operations into agricultural areas in a bid to reduce drought problems experienced by Midland and East Coast farmers.

[1] Glaciogenic seeding is based on promotion of the formation of ice crystals

Figure 1. Targeted cloud seeding catchment areas



1.2 Aim

The aim of this background report is to assess – as far as existing data and natural variability of rainfall allow – the effects of cloud seeding on rainfall on the West Coast.

The Tasmanian scientific studies so far have been aimed at detecting rainfall effects in the targeted areas. The purpose of this study is to review existing evidence of effects of cloud seeding on the West Coast of Tasmania. Part of the West Coast is situated in or directly adjacent to existing target areas. The rest of the West Coast is situated upwind from and in proximity to the target areas.

All previous studies have taken into account the possibility that rainfall effects could occur outside target areas. From these previous studies we have been able to assess and estimate within a broad bandwidth the likely effects of cloud seeding on rainfall in the West Coast area.

We think that at this point it would not be feasible to make better or firmer estimations (with a smaller bandwidth) based on existing data and state-of-the-art science. The scientific studies done so far and interviews with some of the leading scientists have delivered what we believe is the best possible and scientifically substantiated estimate.

1.3 Remainder of this document

Section 2 provides background to the long term rain regime in the west coast of Tasmania.
Section 3 describes cloud seeding in general and experiments to determine its effects.
Section 4 looks at the particular effects on the West Coast local government area
Section 5 provides our conclusions arising from the previous sections.

Appendix A provides long term annual rainfall records at the reference sites
Appendix B provides an overview of seeding operations from 1998 to 2007
Appendix C provides an overview of the relevant literature on cloud seeding.

2 Rainfall and trends West Coast Tasmania

The climate on West Coast of Tasmania can be typified as variable; temperature, wind and precipitation can vary dramatically within a matter of days and sometimes even hours. November is the wettest month and generates 268 mm of rainfall on average in Queenstown (1906-2006). Also, the seasonal differences are great. Autumns generally have the lowest rainfall while springs are extremely wet.

Seasonal rainfall varies greatly from year to year as well. For instance, in 2001, winter rainfall in Queenstown was exceptionally low. The Queenstown rain gauge operated by the Bureau of Meteorology measured 342 mm of rain, while the 100 year long term winter average is 630 mm.

This chapter will discuss in some detail long term rainfall variability and trends in the West Coast of Tasmania mainly by using reliable long term Queenstown data. In addition, comparisons will be made with weather patterns in the north-west, centre and the south of Tasmania.

Reliable long term precipitation data: BoM's high-quality gauges

Rainfall data are collected by the Bureau of Meteorology (BoM) throughout Australia including Tasmania by specific rain gauges. In light of this study long term rainfall data was taken into account to get a perception of the natural variability of rainfall and of long term trends in rainfall. The number of gauges that have been operating continuously for long periods of time is fairly limited. On top of that, during the last hundred years, many gauges have been relocated and in some cases the surroundings have changed dramatically. Even minor changes can have dramatic impacts on the measurements and therefore reliability of the data.

The BoM indicates it has identified twelve high-quality rain gauges in Tasmania which provide reliable long term rainfall data[2]. Within the West Coast there is one high-quality point and it is located in Queenstown. This rain gauge has been operating since 1906. It has been relocated once; the gauge operated at the Copper Mine until July 2002 and a new gauge started operating in South Queenstown in 1996. After tests on data reliability BoM determined the Queenstown gauge returns reliable long-term data and was subsequently defined as a high-quality gauge.

So, for the following long term analysis, there is one reliable long term point at the West Coast. For comparisons within the region it is possible to use rain gauges in Strahan and Rosebery that have been operating for a shorter period of time.

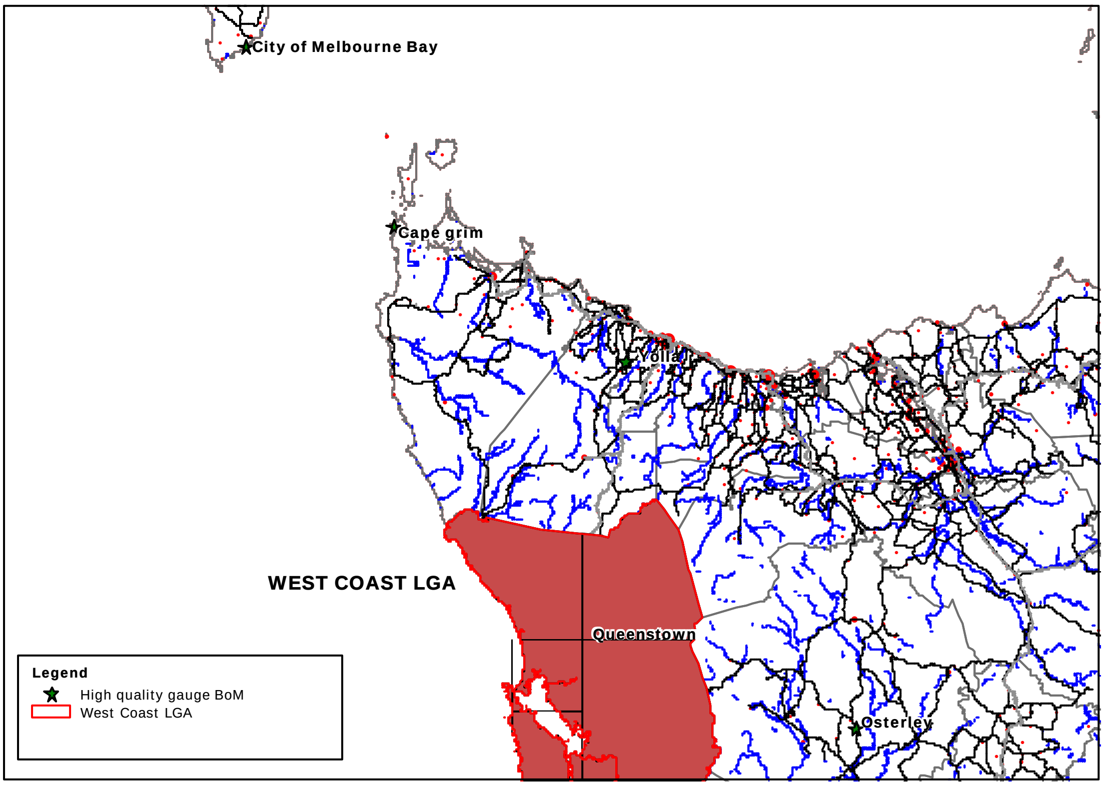
Apart from the Queenstown gauge, the following high-quality points are used for *interregional* comparison (shown on map, Figure 2):

- Cape Grim (far north west)
- City of Melbourne Bay (King Island)
- Osterley (Midlands near Tarraleah)

[2] Although BoM acknowledges 12 of its gauges as high-quality points, the Bureau emphasizes that some inconsistencies still may be present in the data.

- Yolla (northwest, south of Wynyard)

Figure 2. Map indicating five high quality gauges BoM



Source: SGS (2007)

These reference points are at a suitable distance from Queenstown and cloud seeding target areas. The Northwest corners and off-shore islands of Tasmania are very unlikely to be influenced by seeding (confirmed by M. Manton, 4 October 2007).

Rainfall in the eastern half of Tasmania has a markedly different pattern than the west. The east is influenced by different climate systems than the west (Pook, M.J. & Budd, W.F., 2002). Rainfall in the north-eastern half of Tasmania is influenced by El Nino-Southern Oscillation system (ENSO), which is not so relevant for rainfall patterns in the west and the south-west. As a result, variability of rainfall in the eastern and the western half of Tasmania correlate only weakly.

2.1 Natural variability of rainfall

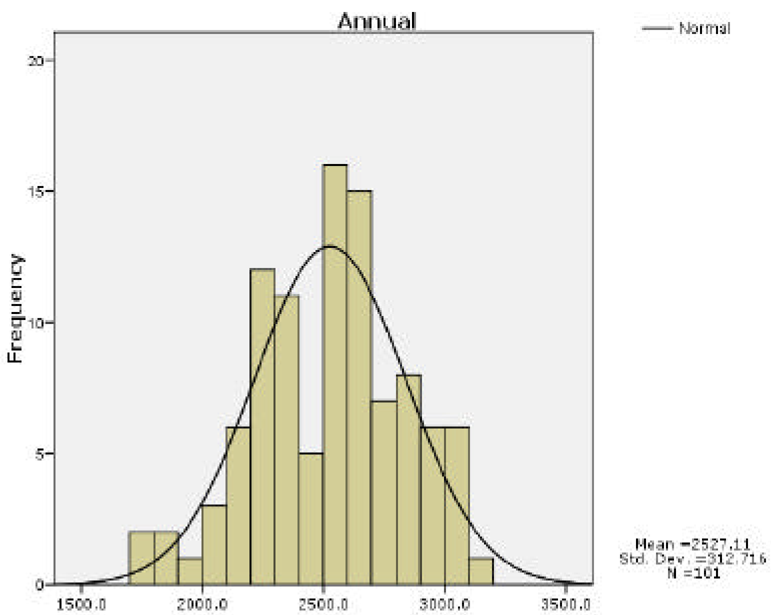
From 1906 to 2006, precipitation (snow, hail and mostly rain) levels have been measured in Queenstown[3].

2.1.1 Annual rainfall and variability

The highest total annual rainfall ever recorded was in 1947 and it equalled 3155 mm. In contrast, Queenstown's lowest annual rainfall in its recorded history was in 1933 and was 1703 mm. On average, Queenstown experiences 2528 mm of rainfall per annum. Looking at the current operational phase of cloud seeding that commenced in 1998, the driest year has been 2000 with a total rainfall of 2132 mm. The wettest year so far has been 2001 when total rainfall reached up to 2901 mm (as mentioned before, in that same year November rainfall was exceptionally low, which is illustrative for seasonal variability).

Usually annual rainfall is somewhere within the range of 2216 and 2838 mm. Approximately 64% of all annual rainfall observations are within the range of mean rainfall plus or minus 313 mm (+/-12%). Furthermore, annual rainfall observations are quite evenly distributed; there is no significant bias towards extremely dry or extremely wet years. Figure 3 illustrates this with a frequency graph and a normal distribution.

Figure 3. Frequencies of total annual rainfall (in mm), Queenstown 1906-2006



Source: BoM (2007), statistical analysis by SGS (2007)

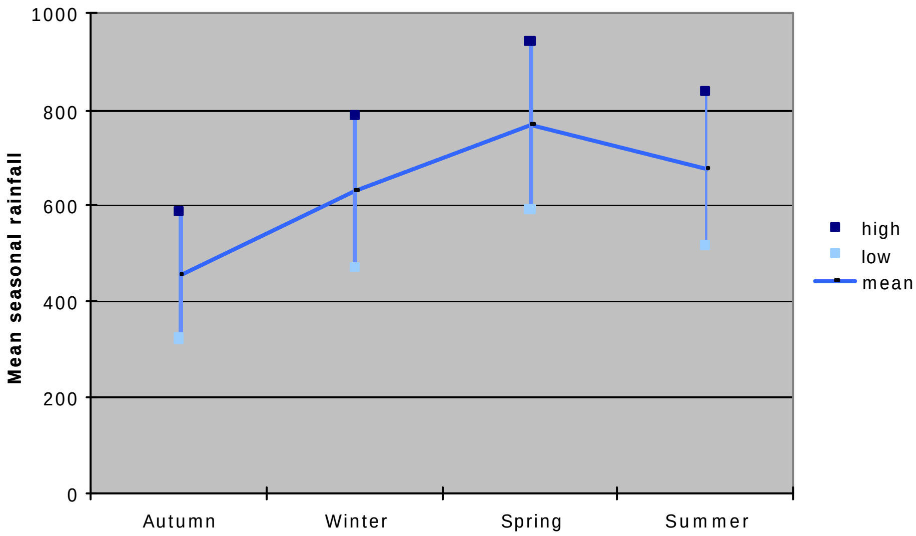
[3] Data for 2005 and 2006 were incomplete; in both years one month of rainfall data is missing. For these months 100 year long-term averages have been used. Manton comments that in-filling data is unnecessary and not good practice, especially when the variability is high.

Annual rainfall variability results from seasonal rainfall patterns. Seasonal rainfall data provide a more detailed picture.

2.1.2 Seasonal rainfall and variability

Total precipitation varies markedly from season to season. Spring (September to November) is usually the wettest season and records 766 mm of rain on average. The driest season is autumn (March to May) and average rainfall equals 454 mm. Mean rainfall is summer is 676 mm and in winter 630 mm. Figure 4 shows the mean seasonal rainfall over the last 100 years, and the high and low ranges within which approximately two thirds of all months have recorded.

Figure 4. Mean seasonal rainfall and high and low rainfall levels in Queenstown, 1906-2006



Source: BoM (2007), statistical analysis by SGS (2007)

Rainfall variability is greatest during spring which is also West Coast's wettest season. During the spring season total rainfall usually varies between 592 mm and 941 mm (s = 175 mm), plus or minus 23% from the mean; 67 of the 100 springs from 1906 to 2006 recorded rainfall totals within this range. The wettest spring ever recorded dates from 1946 with a total rainfall of 1173 mm. The driest on the contrary was in 1956 with 386 mm of rainfall.

Although still considerable, rainfall variability is lowest during autumn which is also the driest season. Rainfall usually varies between 321 and 588 mm. The driest and wettest autumns ever were in 1980 and 1986 with 158 mm and 903 mm rainfall respectively.

In addition to total rainfall, the number of rainy days varies seasonally but with some differences from the amount of rainfall. The average number of rainy days, that is, days with more than 1 mm of rain, by month are shown for several West Coast locations in Table 1. While summer has the most rainfall, it has significantly fewer rainy days than the rest of the year. While spring is the wettest season, winter has more rainy days. For the months from May to October, it rains for more than half of the days each month.

Table 1. Average number of rainy days (>1 mm)

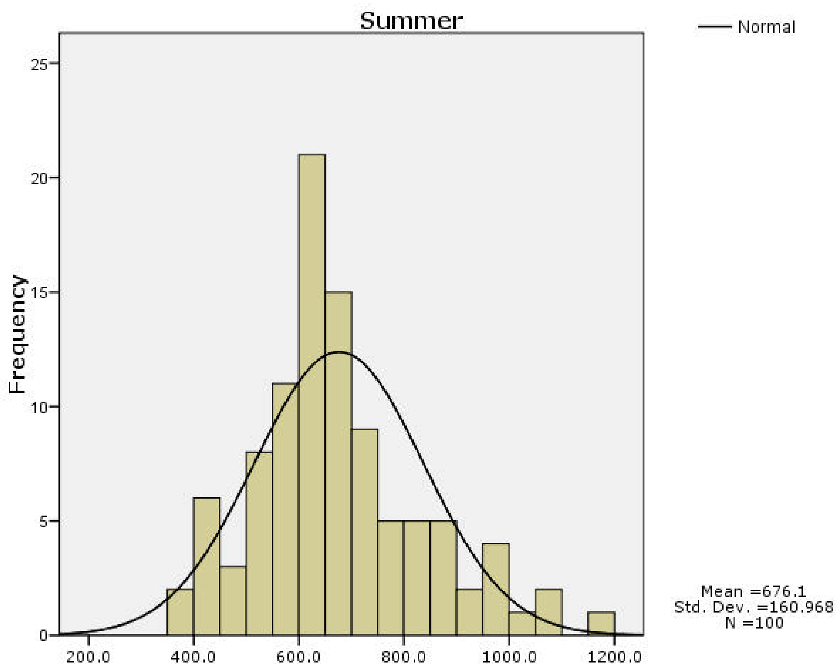
Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Obs	Period
Queenstown	13.3	10.3	13.9	16.8	17.2	16.5	20.0	21.1	19.1	18.3	16.0	15.3	197.8	30	1964-1995
Rosebery	13.8	9.5	12.0	14.1	15.9	17.7	18.7	20.7	20.2	18.3	13.7	13.6	188.2	14	1979-1993
Strahan	10.3	7.9	12.0	12.6	15.7	16.2	17.3	19.2	17.3	15.1	10.0	10.8	164.4	21	1981-2008
Zeehan	11.6	10.1	12.7	15.3	15.8	15.1	16.8	17.9	16.6	16.3	15.0	13.4	176.6	67	1890-1968

http://www.bom.gov.au/climate/averages/tables

Extreme high rainfall seasons

On the seasonal level, the distributions of rainfall observations covering 100 years are less extreme than the monthly distributions evidenced before. The reason behind this is that monthly extremities are 'levelled out' over longer time periods of three months.

Figure 5. Frequencies of total Summer rainfalls (in mm), Queenstown 1906-2006



Source: BoM (2007), statistical analysis by SGS (2007)

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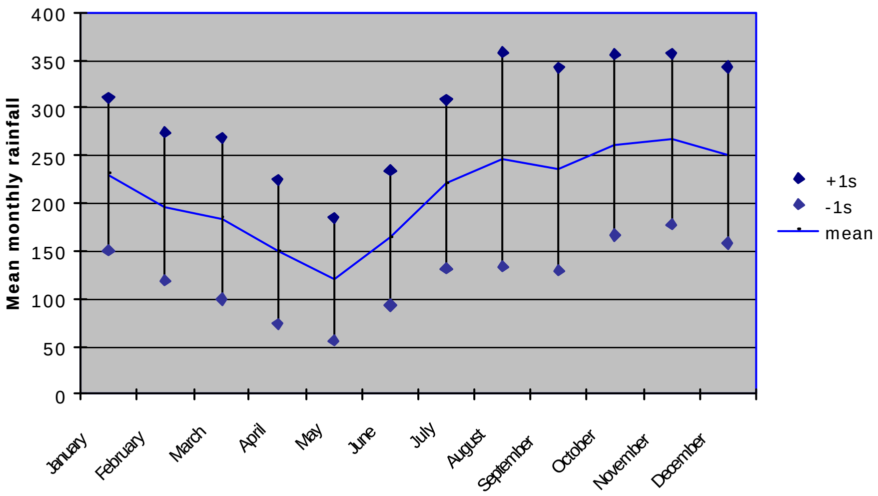
Only the summer season shows a biased distribution; most summers show rainfall totals below or near the average (Figure 5 above) while a limited number of summers experienced much higher rainfall. During four summers extreme high rainfall has occurred (more than 998 mm[4]). This happened in 1914, 1927, 1967 and 1995[5].

2.1.3 Monthly rainfall and variability

Rainfall on the West Coast of Tasmania varies strongly from month to month (Figure 6). April, May and June are the driest months while October, November and December produce the highest rainfall averages. In general, rainfall is lowest in May with 121 mm on average. April and June generally experience rainfall between 150 and 160 mm. The wettest months from August through to December show average rainfalls of between 240 and 270 mm per month.

Figure 6. Mean monthly rainfall and high and low rainfall levels in Queenstown, 1906-2006



Note: The range of values shown are equal to the monthly average plus one standard deviation (+1s) and low values to monthly average minus one standard deviation (-1s). Values fall within one standard deviation about two thirds of the time. The most extreme values are much higher and lower than these.

Source: BoM (2007), statistical analysis by SGS (2007)

Apart from marked rainfall differences between the months, rainfall tends to vary strongly in the same months from one year to the other. Rainfall in January (230 mm on average) for instance, usually varies between 150 and 310 mm. This is the average plus or minus 35%! The spread of observations around the mean is statistically expressed by the standard deviation (s).

[4] Which corresponds with the mean plus 2*s

[5] With total rainfalls of 1174, 1081, 1097 and 1029 mm respectively.

Approximately two thirds of all monthly rainfall observations lie between the mean minus 1 standard deviation and plus 1 standard deviation. In the graph above this is represented by the range between +1s and -1s observations.

The graph shows the normal variability of rainfall around the mean is large. Especially during the wetter months, from August through to December (including), the variability of rainfall is high. Rainfall variability is greatest for August where total rainfall usually is between 134 and 359 mm (s = 113 mm) or 46% beneath or above the average. However the highest recorded August rainfall over the last 100 years fell in 1947 and accounted for 556 mm of rain much greater than the range shown in the graph. Similarly the lowest August rainfall was recorded in 1973 was much lower than the range shown, the gauge measuring just 46 mm of rain. September also shows a high rainfall variability with rainfall usually between 130 mm and 343 mm (s = 107 mm).

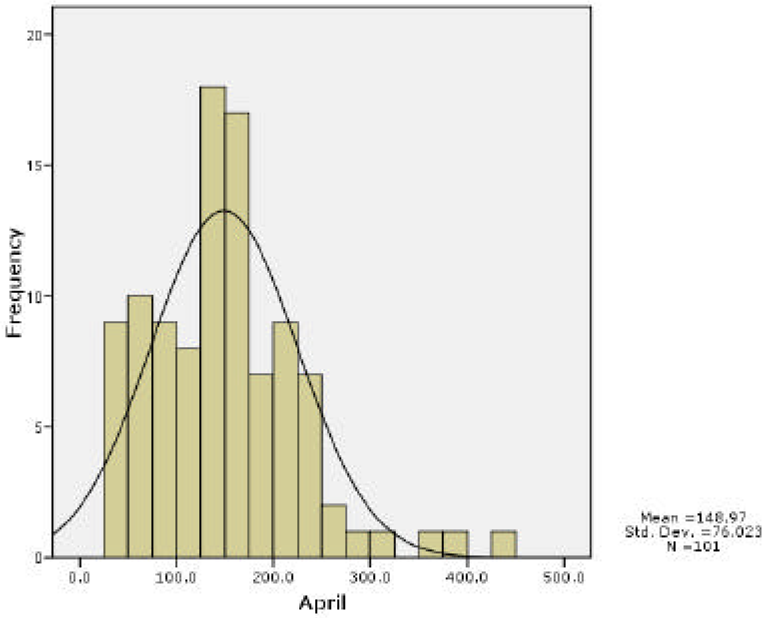
Rainfall variability is smallest during the drier months of April, May and June. Still rainfall variability is considerable. For instance, in May, which is the 'driest' month, rainfall usually varies between 57 and 185 mm.

Extreme high rainfall months

When looking at exceptional rainfall months in more detail, the data reveal that most months record rainfall somewhat below the average. The average monthly rainfall is pushed up by a limited number of months with extreme high rainfall. This can be concluded from skewness analysis of the distribution of observations. The bias is foremost true for the months January through to April and the spring month of September. April seems to be a month that is particularly plagued by extreme rainfall events. For example, Figure 7 shows the frequency graph for April rainfall observations over 101 years (1906 to 2007). Most months recorded rainfalls below and near the average of 149 mm. There were four months between 1906 and 2007 that recorded extreme rainfall totals of 300 mm[6] and up to nearly 450mm, three times average levels.

[6] Which is the mean plus 2*s

Figure 7. Frequencies of total April rainfalls (in mm), Queenstown 1906-2007



Source: BoM (2007), statistical analysis by SGS (2007)

Extreme high rainfall months have occurred the least during October and November months; these months are consistently wet. Therefore, the distribution of rainfall for these two months does not show any significant bias[7] towards extreme high or low events.

2.1.4 Local rainfall variability

Mike Manton, Professor at Monash University and specialist in weather modification and cloud seeding, indicates that at a local level geographical rainfall variability can be very high: one can find 30% differences over a distance of a few hundred metres for an individual storm.

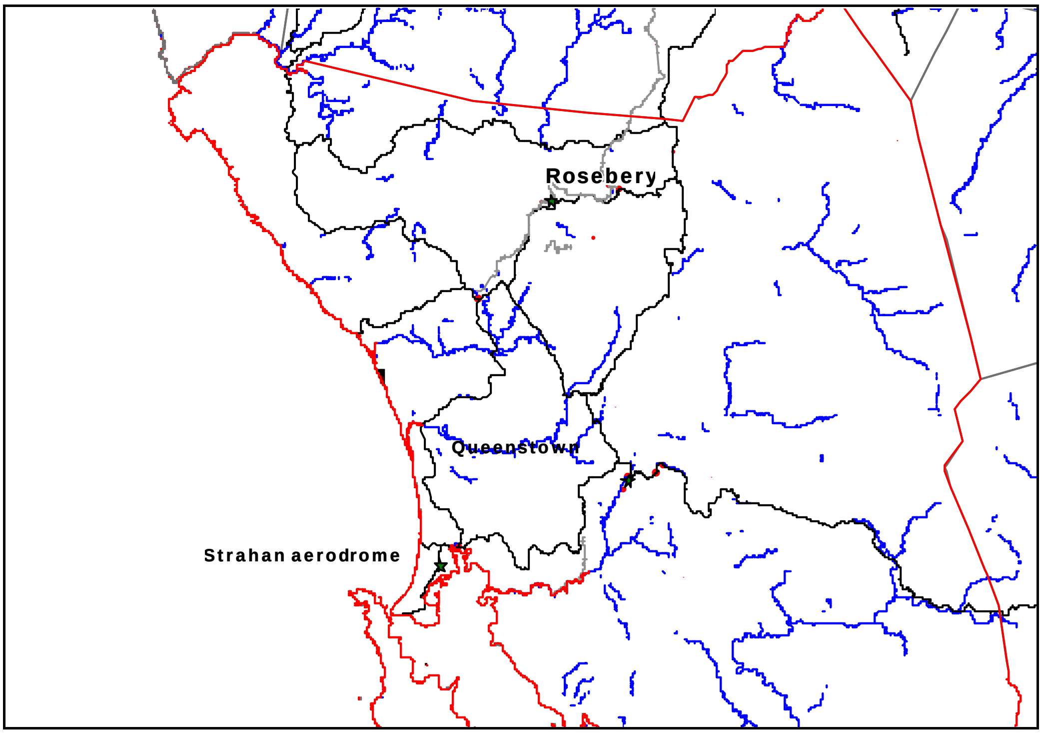
BoM publishes rainfall data recorded at specific locations on its website. Rainfall data from Queenstown, Rosebery and Strahan (map, Figure 8), roughly covering the timeframe 1980 to 2006[8], were used to provide some insight in rainfall variability between townships of the West Coast[9].

[7] Z-score of skewness is 0.5 for October and 0.8 for November months.

[8] Data from Rosebery only cover 1979 to 1993 when the gauge closed.

[9] Zeehan rainfall data were not included in the analysis because no data are available for the period 1980 to 2006. The gauge was closed years ago with its last records referring to 1967.

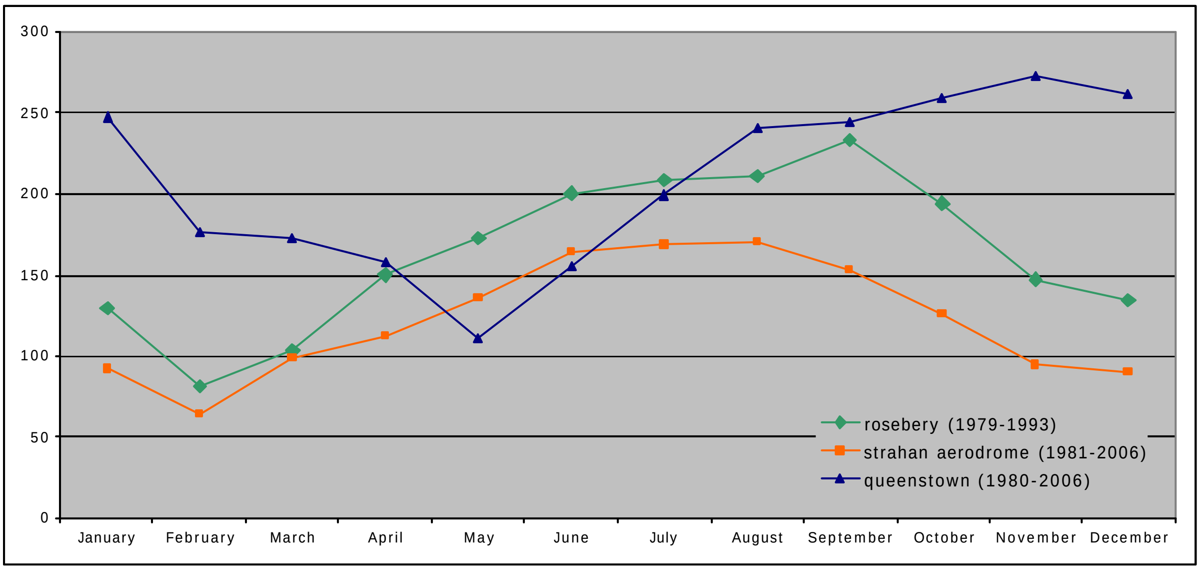
Figure 8. Location of three local gauges in Queenstown, Strahan and Rosebery



Source: BoM (2007)

Rainfall patterns vary considerably between the towns. While rainfall is highest in Queenstown during most months, both Strahan and Rosebery have higher rainfall averages in May and June (Figure 9). Especially in November, December and January average rainfall in Queenstown is much higher than elsewhere.

Figure 9. Mean monthly rainfall in Queenstown, Rosebery and Strahan, in mm, 1979-2006



Source: BoM (2007)

2.2 Precipitation trends

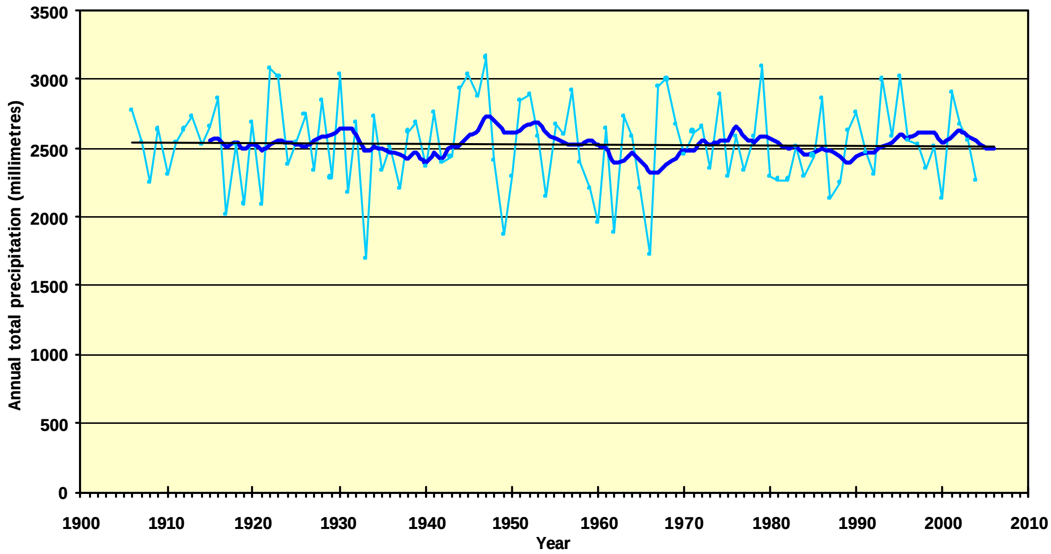
The previous sections clearly illustrated the high variability of rainfall on the West Coast. This section aims to identify any trends or long-term changes in rainfall.

Figure 10 below shows annual rainfall from 1906 to 2006 for Queenstown. The light graphline represents total rainfall per annum while the dark graphline shows the rolling 10-year average and shows decadal variability. Thirdly, the straight line is a long term trendline, indicating any trends in rainfall over the entire period.

On the annual level and on a 100 year time scale, no apparent or outstanding trend in terms of precipitation is discernible in Figure 10. Annual rainfall averages 2527 mm per annum. The long term trendline suggests a somewhat downward trend, but the slope of the line is too flat to speak of an obvious trend. There seems to be a reduction in variance since the 1970s showing fewer drier years. Manton comments there have been changes in the large-scale climate of southern Australia since the 1970s, which have nothing to do with local features like cloud seeding.

Between 1990 and 2002 roughly, annual rainfall records were somewhat above the long term average. Recent years of low precipitation have turned this movement around again.

Figure 10. Annual total precipitation in Queenstown, 1906-2006



Source: BoM (2007)

Reference locations Cape Grim, City of Melbourne Bay (CMB) on King Island, Yolla and Osterley reveal various long term trends in precipitation. At both Cape Grim and CMB annual rainfall follows a trend of increasing rainfall. The results for the reference sites are shown in Appendix A. In Yolla and Osterley on the other hand there is a downward trend in annual rainfall visible.

Annual rainfall varies strongly from town to town; the correlation between annual rainfall in Queenstown and the other sites is each low between 0.2 and 0.4 on a scale of 0 to 1 (Table 2).

Queenstown has the highest rainfall by far, followed by Yolla. Overall rainfall at the different locations is very different from one to the other. Apart from that the table below clearly shows rainfall variability is great at all these sites.

Table 2. Annual precipitation at selected high-quality gauges, in mm, 1906-2006

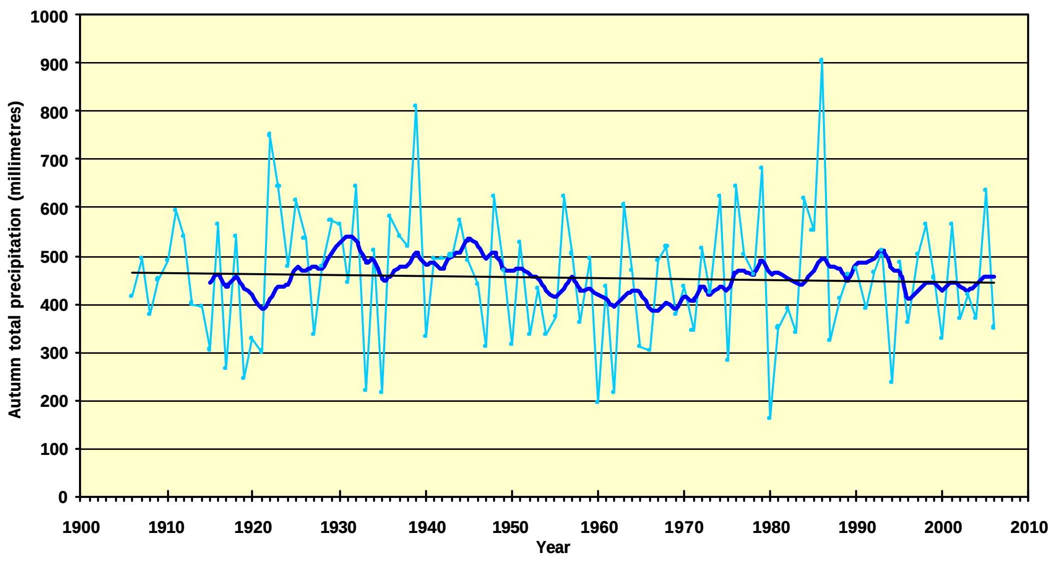
Gauge	Mean annual precipitation	Correlation with Q'town	Minimum mm	Minimum year	Maximum mm	Maximum year	Records since
Queenstown	2527	1.0	1703	1933	3155	1947	1906
Cape Grim	947	0.2	608	1914	1379	1968	1896
CMB	1024	0.4	723	1913	1458	1951	1909
Yolla	1444	0.4	902	1913	2271	1974	1905
Osterley	716	0.4	428	1919	1095	1934	1910

Source: BoM (2007)

When looking at the data in more detail it becomes clear that seasonal trends determine these annual outcomes. The following discusses underlying seasonal trends in precipitation.

Autumn rainfall in Queenstown shows an apparent downward trend[10] from 1906 to 2006 (Figure 11). A similar trend can be observed in Yolla and Osterley. Autumn rainfall in CMB follows a stable trend, while Cape Grim shows increasing autumn rainfall (Appendix A). Especially in the early nineties there was a significant temporary drop in autumn rainfall.

Figure 11. Total autumn precipitation in Queenstown, 1906-2006



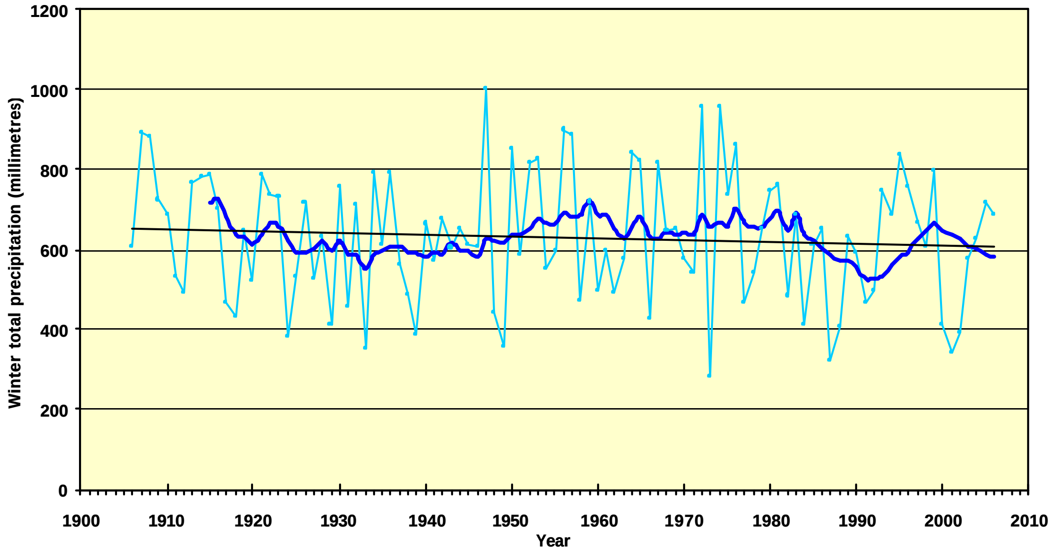
Source: BoM (2007)

Winter rainfall too shows a somewhat downward trend in Queenstown (Figure 12). The same trend is seen in Yolla, while winter rainfall in Osterly and CMB show flat trendlines. In Cape Grim, winter

[10] The trends identified are not statistically significant due to the high natural variability.

rainfall has increased over the long term. Between 1990 and 2000 (roughly) rainfall showed an upward trend which was halted around 2001. Overall, rainfall variability between years and decades is very high.

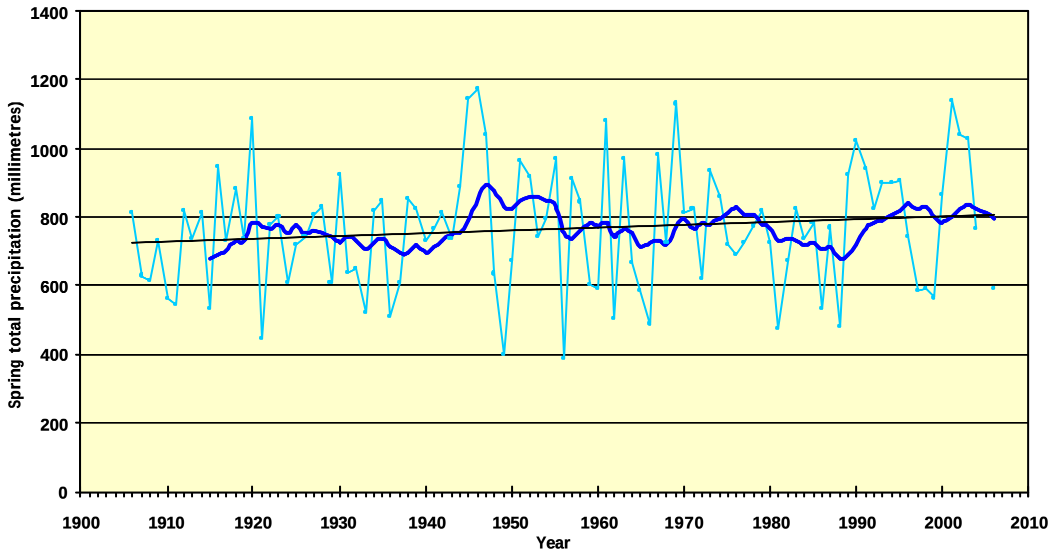
Figure 12. Total winter precipitation in Queenstown, 1906-2006



Source: BoM (2007)

Queenstown's decreasing rainfall patterns during autumn and winter are compensated by a long term increase of rainfall during spring. Although variability from year to year is great, overall an upward sloping trend is disce rnible (Figure 13).

Figure 13. Total spring precipitation in Queenstown, 1906-2006

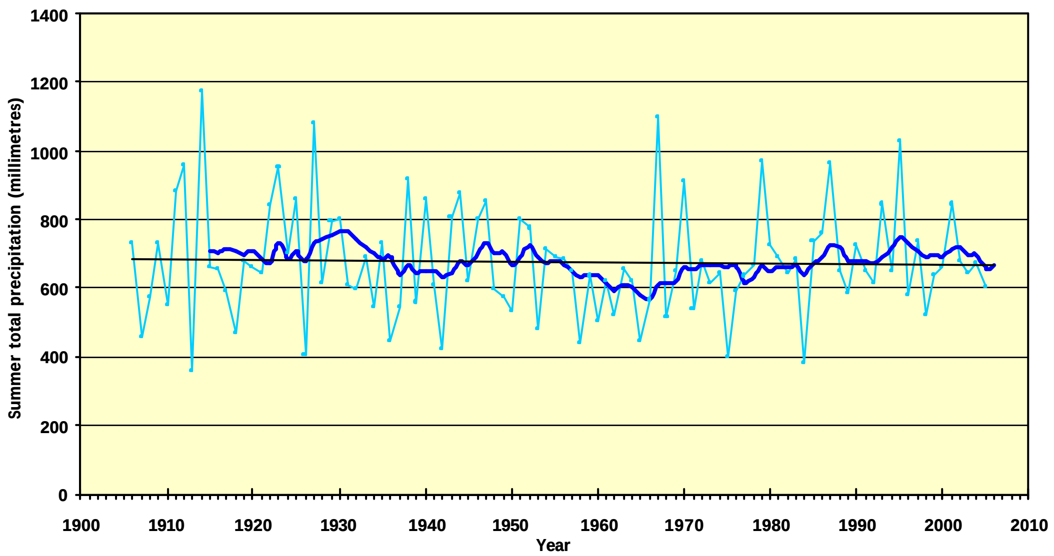


Source: BoM (2007)

A similar trend is seen in CMB, where the trend is relatively strong. However, the other reference sites show the opposite trends.

Finally, summer rainfall in Queenstown has followed a stable long term trend over the last 100 years (Figure 14). This trend is consistent with the four reference sites which all show long term stable rainfall (Appendix A).

Figure 14. Total summer precipitation in Queenstown, 1906-2006



Source: BoM (2007)

There is little evidence of any significant change in the trend of the annual rainfall in Queenstown. The key message is that rainfall variability is high; there have always been large variations from year to year and from decade to decade. While autumn and winter seasons seem to become less wet, most of this is compensated by a trend of increasing spring rainfall. Rainfall at the reference sites all follow individual trends although rainfall in Yolla shows most similarities with Queenstown.

2.3 Conclusions

The previous sections have shown overall rainfall in Queenstown is high, averaging over 2500 mm per annum. Moreover, the natural variability of rainfall is very high. It is not unusual for seasonal rainfall to vary plus or minus 23% from the average from one year to the other. Monthly rainfall varies even more; August rainfall usually varies between 46% below or above the average. Extreme rainfall seasons or months are at an even further distance from the mean. None of the extreme high rainfall months occurred within the current operational phase of cloud seeding. Most extreme rainfall months occurred prior to 1948.

The high natural variability has drastic consequences for the scientific statistical analysis of the effects of cloud seeding on rainfall. The high background noise makes it extremely difficult to discern cloud seeding effects. One needs to perform long term experiments to be able to produce conclusive scientific evidence. "Even in the best experiments, it has taken more than a hundred seeded days to detect with any confidence, a 10% increase due to seeding", (Bigg, E.K. & Turton, E., 1988). In addition, these experiments need to meet certain stringent design criteria in order to deliver useful data at all.

Long term rainfall data do not reveal any obvious trend in annual precipitation for Queenstown. However, there seems to be a shift in seasonal rainfall patterns. Autumn appears to have become drier over the past 100 years while late winter and spring have been experiencing increasing rainfall. At the annual level these two movements largely compensate each other. Such apparent trends occur against a background of large inter-decadal variability. The reference rain gauges, BoM's high quality gauges at Cape Grim, City of Melbourne Bay, Osterley and Yolla, all have significant lower rainfall than Queenstown. Rainfall variability at these sites is high, just as in Queenstown. Rainfall trends at CMB seem to correlate reasonably with Queenstown while the remaining three references show quite different trends. It shows rainfall patterns vary strongly from one place to the other.

This becomes even more apparent at a local scale when comparing rainfall statistics of Queenstown with Strahan and Rosebery; the amount of rainfall per month varies strongly between the towns.

3 Cloud seeding methods and effectiveness

This chapter discusses the concepts associated with cloud seeding in Tasmania, past efforts to understand its physical operation and effectiveness.

3.1 Cloud seeding – a brief history

Cloud seeding is a process to attempt to change the amount or type of precipitation that falls from clouds, by dispersing substances into the air that serve as cloud condensation or ice nuclei. The most common aim is to increase precipitation, although it has been applied to reduce the risk of hail damage as well. For instance, until 45 years ago rockets filled with silver iodide were shot up in the air in the Huon Valley in an attempt to prevent hail storms damaging apples.

Vincent Schaefer, a General Electric chemist, executed the first glaciogenic cloud seeding experiments in 1946 by dispersing dry ice from a plane into the clouds. Since then numerous experiments have been conducted with various results. Several seeding agents have been used but most common are the use of silver iodide (AgI) and dry ice.

Since the first experiments knowledge about cloud seeding has increased significantly. Cloud seeding is claimed to be effective under certain circumstances. Glaciogenic seeding of clouds requires that they contain supercooled liquid water – that is, liquid water colder than zero degrees Celsius. Other circumstances related to effective cloud seeding are concerned with cloud depth, temperature, convection and orographic uplift. Cloud depth is important to ensure that the seeded clouds are deep enough to allow time for ice crystals to grow and fall out as precipitation particles. On the other hand, silver iodide is effective only over a certain temperature range and so the cloud-top temperature needs to be appropriate. There is some evidence that the clouds in Tasmania most susceptible to cloud seeding are of stratus rather than cumulus type, and that supercooled liquid water is most likely to occur when the air is being lifted as it passes over the mountains.

It is therefore usual to ensure that a number of meteorological conditions are satisfied before seeding is commenced. A key condition is that the seeding material released into the air is likely to lead to precipitation in the target area.

3.2 Cloud seeding experiments - overview

Since 1947 major research programs have been conducted in the USA (eg the Climax experiments), in Israel and in Australia. Although the experiments of both the USA and Israel were initially claimed successful, critique followed in regard to the design and analysis of data. Rangno and Hobbs (1993) argue these experiments fail to establish sufficient proof of the efficacy of cloud seeding. They do not argue the Australian experiments were flawed.

Cloud seeding investigations can consist of two types of research and preferably combine both:

1. Statistical programs aimed at measuring increased precipitation in target area using a randomised seeding schedule, and;
2. Physical programs aimed at determining and understanding the precipitation process.

Physical studies can provide plausibility and understanding to any statistical inference of cloud seeding effectiveness (Ryan & King, 1997). Given the availability of modern observing technology, any reputable cloud seeding experiment needs to include physical measurements, as well as statistical analyses, to assure the validity of the basic seeding hypothesis (comment by Manton, November 2007).

Internationally, there is still no complete scientific consensus on the effectiveness of cloud seeding: "there still is no convincing scientific proof of the efficacy of intentional weather modification efforts" (U.S. Weather Modification Research and Operations, 2003).

The issues in establishing conclusive scientific proof on the effects of cloud seeding are largely due to poor design of experiments to take into account the high background "noise" of natural variability in rainfall, and to test the physical hypothesis underpinning the science.

The World Meteorological Organization (WMO) developed guidelines in regard to experimenting with cloud seeding. Before starting experimenting the following criteria should be met according to the organisation:

- Clouds suitable for seeding have to occur reasonably frequently;
- Rain patterns need to be such that there is a reasonable chance of establishing evidence of seeding effects within 5 years, and;
- The costs of the experiments are well below the economic benefits.

The first point indicates the weather system should at least have some potential for rainfall enhancement. Higher frequency of seeding also helps develop a large enough sample to address the second point of developing sufficient evidence. The second point also refers to the natural variability or background noise mentioned earlier. The third point ensures long term commitment of resources to the experiment, minimising the chance of it being cancelled prematurely. Since the experiment in the wheat belt of western Victoria (1979-80) these guidelines have been applied by CSIRO to subsequent experiments.

The effectiveness of cloud seeding and of establishing scientifically well founded proof is limited to certain meteorological conditions: stratus clouds undergoing orographic uplift seem most favourable in this regard in Australia (Ryan & King, 1997). However, the Queensland Government is currently running a cloud seeding experiment aimed at examining the scientific feasibility of cloud seeding in the cumulus clouds of the sub-tropics.

3.3 Cloud seeding experiments in Australia

Between 1947 and 1994 a number of cloud seeding experiments were conducted in Australia. The early experiments can be described as 'black boxes' providing no insight in the underlying physical processes. Over time these evolved to 'gray boxes' where direct observations of physical aspects were incorporated. The later experiments included both statistical evaluation and a physical analysis of the process.

The first experiments by CSIRO consisted of dispersing dry ice as seeding agent into single clouds. Observations showed obvious reactions in the cloud formation and precipitation from these clouds shortly after the agent was applied.

The four CSIRO experiments between 1955 and 1963 produced generally disappointing results. Although the Snowy Hydro experiment returned evidence for 19% additional rainfall due to cloud seeding, the remaining three experiments were inconclusive. The design of the experiments may have been the cause of that. Bigg & Turton claim to have found evidence for persistence effects of cloud seeding using silver iodide as agent. They argue the design of the experiments did not allow for persistence effects. There still is no conclusive scientific evidence for their claims on the existence and extent of persistence effects (Ryan & King, 1997). (The subject of persistence is discussed in more detail in section 4.3.2.) In response to the outcomes CSIRO adjusted its design protocols for subsequent experiments.

The first Australian experiment to incorporate the adjusted CSIRO design protocols was Tasmania's first experiment, conducted between 1964 and 1971. The experiment returned evidence of increased rainfall due to cloud seeding in autumns (+30%) and Tasmania's Hydro-Electric Commission (HEC) subsequently decided to further explore cloud seeding operations. The second Tasmanian experiment meant a shift away from the black box approach towards a grey box approach. It introduced the concept of suitable seeding day based on a range of physical weather observations. This experiment too produced some successful results as returned scientific substantiated statistical evidence cloud seeding enhanced precipitation by up to 37% in weather conditions where clouds were pushed up against the mountain ranges.

The HEC commenced a third phase of cloud seeding from 1988 to 1991. This was focused on operational goals rather than objective scientific ratification of the effects of cloud seeding. The program aimed to increase rainfall in a period of drought. Due to its operational focus it produced no relevant scientific insights. In 1998 Hydro Tasmania (formerly HEC) commenced its current operational phase of cloud seeding in order to enhance rainfall in its hydro-electric catchment areas. Hydro Tasmania made this decision based on the positive results of previous experiments.

Hydro Tasmania conducted drought relief cloud seeding operations over Tasmanian agricultural areas in 1973, 1994, 1995 and 2000.

After the experiment for Melbourne Water Corporation (1988-92) no cloud seeding experiments were conducted in Australia until 2004. In 2004 Snowy Hydro started a six year experiment. Climate change and recent (ongoing) droughts in the South-East of Australia are the underlying reasons for the regained attention for cloud seeding. The renewed interest in cloud seeding is also evidenced by the fact that in May 2007 the Bureau of Meteorology Research Centre (BMRC) organised a cloud seeding research symposium. One of the results of this meeting was the establishment of a working group whose aim it is to focus and coordinate research on precipitation enhancement, including the physics and chemistry of clouds. Table 3 summarises Australian experience.

Table 3. Overview of Australian cloud seeding experiments 1947-2007

Locations, years	Lead by	Clarifications, comments
1947-56	CSIRO	Single cloud experiments. Silver iodide and dry ice were used as agents. The successful results led to CSIRO embarking on a program of area experiments.
Snowy Mountains, New England, Warragamba, SA (1955-63)	CSIRO	A randomisation scheme determined area and control area[11]. The Snowy Hydro experiment returned significant results of +19% rainfall, while the results of the remaining three were inconclusive[12]. The experiments showed decreasing results over time which may have been caused by persistence effects.
Vic, NSW, Qld, SA and WA (1965-71)	State governments	These were primarily of an operational nature. As a consequence, the data did not deliver conclusive experimental evidence. A long term debate evolved on the results of the Victorian operation in 1966, which in the end affected the credibility of cloud seeding in the scientific community (Ryan & King, 1997)
Tasmania Exp I (1964-71)	CSIRO, HEC	Design included target and three (non-seeded) control areas and a randomisation scheme of seeded and unseeded periods of appr. 12 days. Also, it included seeded and unseeded years to ensure analysis was not contaminated by persistence (if any). Results indicate 30% increase in precipitation in autumn with significance level of 97%. Results were inconclusive for other seasons. HEC decided to further explore cloud seeding as a means for water resources management. Silver iodide was used as seeding agent. Ratio seeded period versus non seeded period was 1:1.
Tasmania Exp II (1979-83)	CSIRO, HEC	The experiment introduced and applied the concept of suitable seeding day (instead of any 12 day period) based on better understanding, better physical observation and usage of equipment to determine suitable conditions. Ratio seeded verses unseeded days was 2:1 and final sample included 66 days. Seeding was performed 1 hour upwind from target area in case of stratiform clouds and 0.5 hour for cumulus clouds. The results show increased rainfall of up to 37% for stratiform clouds in southwest through west to northwesterly air streams undergoing orographic uplift. Evidence for downwind effects was not produced which may be due to limited sensitiveness of statistical analysis in light of high natural variability of rainfall.
Emerald (1972-75)	CSIRO	Experiment aimed at seeding of cumulus clouds. Enhanced rainfall was expected to be valuable for irrigation and mining. Both dry ice and silver iodide were used as agents. Establishing statistical evidence was complicated by extreme spatial and temporal variability of natural rainfall in the area. It was concluded it would take many years of experimenting in order to establish a statistical and scientifically reliable answer. Due to the required long term commitment of resources the experiment was abandoned.

[11] In hindsight this is seen by Bigg and Turton as a major flaw in the experimental design. Persistence effects may have caused decreasing effectiveness and even negative effects over time.

[12] Two experiments even produced negative outcomes, however the significance level for this was low.

Western Victoria (1979-80)	CSIRO	Experiment in a major wheat growing area aimed at increasing crop revenues using cloud seeding to enhance rainfall. The experiment was based on WMOs guidelines, used the definition of 'suitable day' from the Tasmanian experiment and included a physical program. After two years it was concluded that the occurrence of suitable seeding conditions was grossly overestimated prior to the experiment. Based on adjusted analysis it showed the experiment was no longer economically viable and subsequently abandoned.
Northern wheat belt WA (1980-82)	?	The occurrence of suitable clouds was reasonable. Simulations showed that a 30% rainfall enhancement required a 5-year experiment to establish evidence and a 10% enhancement required a 20-year experiment. The benefit-cost ratio was optimistic. Nonetheless, there was insufficient commitment for delivering 20 years of resources and the experiment was halted.
Greater Melbourne (1988-92)	Melbourne Water Corporation, CSIRO	Experiment aimed to enhance rainfall in MWCs catchment area by seeding stratiform clouds. Conditions as oropgraphic uplift and cloud tops above -10°C proved favourable. The overall results remained inconclusive and have not been published.
Tasmania Exp III (1992-94) Dry Ice Cloud Seeding Experiment (DISCE)	HEC	The three year experiment used dry ice as a seeding agent. This experimental phase did include a 2:1 randomisation (Searle & Nebel, 1998). The results of the seeding are generally regarded as inconclusive due to the experiment's design and related analysis (pers comm., Morrsion 2007; confirmed by M. Manton, Nazarov).
Tasmania IV, 1998-ongoing	Hydro Tasmania	Cloud seeding activities are of an operational nature. The operations do not include a randomisation scheme (suitable but unseeded days). As a consequence analysis is confined to historical data analysis and Mike Manton (as well as Ryan & King, 1997 among others) confirms it would be desirable to impose some randomisation on the operations. See more in section on current operational phase. Alex Nazarov agrees it would provide a better understanding of the process and eventually optimise the efficiency of Hydro Tasmania's operations. Manton mentions that Hydro Tasmania's current mode of operation makes it impossible to know if cloud seeding has an impact. The longer Hydro Tasmania continues this mode, the less likely historical data analysis will be valid in future.
Snowy Mountains NSW (2004-10)	Snowy Hydro Ltd	Snowy Hydro is conducting a six-year research project of winter cloud seeding to assess the feasibility of increasing snow precipitation in the Snowy Mountains. Silver iodide is the seeding agent being dispensed from ground based aerosol generators. An 11 member Independent Scientific Expert Panel assessed the project. The conclusion from the panel members is that the Snowy Precipitation Research Project would not have a significant adverse impact on the environment. In addition, the panel noted that there are no statistically significant indications that rainfall/snowfall decreases downwind from any long term winter seeding projects. The results of the experiment are not yet known.
Queensland (2008-2010)	Queensland Climate Change Centre of Excellence	The Queensland Climate Change Centre of Excellence has commenced a Cloud Seeding Research Program aimed at establishing the feasibility of cloud seeding in south-east Queensland. The program involves collaboration with the Bureau of Meteorology, CSIRO, University of Southern Queensland and Monash University as well as the USA National Center for Atmospheric Research.

Source: Ryan & King (1997), SGS (2007)

3.4 Statistical analysis and experimental design

Over time and often steered by the quality of data available, scientists have applied various statistical methods to assess the effectiveness of cloud seeding. Since the first experiments in 1946 a wide range of scientific analyses and publications on the effects of cloud seeding have emerged. Overall, two types of statistical analysis have been applied regularly:

- Single ratio or percent normal analysis / historical analysis
- Double ratio analysis

Long term historical analysis of rainfall data or percent normal analysis[13] aims to assess the effects of cloud seeding by comparing historical rainfall data of the target and one or more control areas with rainfall in seeded periods. The method is often applied in operational phases when no randomised unseeded (but suitable) periods are defined

Among scientists there is wide agreement that the single ratio analysis provides only limited evidence on the effectiveness of cloud seeding. According to Shaw, who commented on Pook and Budd's evaluation of cloud seeding in Tasmania, the percent normal analysis is seen as a contentious approach for evaluating the effects of cloud seeding (Shaw, 2002). The results are often seen as biased because seeding takes place in periods that are wetter anyway. When applying this type of analysis some comparison is often made with control areas. However, it is important to note that one of the prime characteristics of rainfall is its high temporal and spatial variability. In this regard Mike Manton notes that after a reasonable storm total rainfall can easily be 30% higher or lower at one location than at another location only a few hundred meters away. Spatial variability is also strong on a monthly, seasonal or even annual level.

Furthermore, long term historical analysis by its very nature is sensitive to long term trends in climate and precipitation patterns which by chance may coincide with cloud seeding experiments. The most reliable methodology, according to the majority of scientists, is double ratio analysis or similar.

Double ratio analysis[14] is the preferred methodology if a seeding experiment allows for a randomisation scheme of suitable but unseeded time units (days or longer periods). By comparing unseeded suitable days with seeded suitable days, the analysis is based on comparison of days with the same potential for rainfall, so that bias is greatly reduced. Since the early days of cloud seeding, there is now a clearer understanding of suitable conditions. Also, technological progress makes it possible to observe detailed weather conditions with greater precision. These factors have contributed to the scientific design and analysis of experiments.

Apart from randomisation, the double ratio analysis should also incorporate control areas that are not seeded on any occasion. In choosing appropriate control areas it is important that:

- rainfall patterns in the area correlate strongly with the target area, and;

[13] Another name is 'single ratio analysis'

[14] Double ratio: (A/B)/(C/D) where A = rainfall in target area during seeding period, B = rainfall in target during unseeded period, C = rainfall in control area during period in which target is seeded, and D = rainfall in control area during unseeded period in target.

- rainfall in the area should very unlikely be affected by seeding operations for the target area, usually being upwind or distant locations.

For Tasmania most scientists indicate the Northwest of state as being most appropriate in this regard. Strathgordon has been utilised as an appropriate control area in some studies depending on the targeted areas of the experiment in progress.

To obtain reliable estimates of rainfall over the target or control areas, a network of suitably spaced rain gauges is required. The network should operate consistently over the duration of the experiment to avoid measurement bias, and ideally historical data should be available from the same network to support the initial design of the experiment.

3.5 Summary of findings

The review of experiments and findings shows that clear evidence of the effectiveness of cloud seeding is often elusive. Of all of the areas in the world, evidence for effectiveness appears to be strongest in the western portion of Tasmania's Central Plateau.

Overall, the cloud seeding experiments show seeding is most effective in certain weather circumstances. Clouds should already have a high supercooled liquid water content in order to be suitable for seeding (Ryan & King, 1997). The premise is that cloud seeding can improve the efficiency of precipitation by the introduction of artificial ice nuclei into clouds deficient in naturally occurring ice nuclei as evidenced by high supercooled LWC. The relationship between supercooled LWC and precipitation is not straightforward but results from Stage II suggest that Tasmanian cloud seeding operations are effective in increasing rain on an already rainy day.

Cloud seeding is potentially effective in regions where clouds frequently undergo orographic uplift; i.e. mountainous areas. The most suitable clouds are stratus clouds in a maritime airstream and cloud tops between -10°C and -12°C (Ryan & King, 1997; Smith et al, 1979). Both circumstances prevail on the Tasmanian West Coast. Tasmania is also the place where the most successful experiments have been conducted in Australia.

4 Cloud seeding in Tasmania

As discussed in a previous section, most mainland Australia experiments did not produce conclusive evidence of the effectiveness of cloud seeding or were criticised for the quality of their experimental design and related statistical analysis. The only mainland scientifically accepted study with statistically significant increase in rainfall is the Snowy Hydro experiment (1955-59).

In contrast, the Tasmanian experience has been successful. The Tasmanian experiments (I and II) over Tasmania's Central Plateau are regarded by most scientists as providing reliable scientific evidence based on properly designed experiments. In addition, most scientists agree the results show there is strong evidence that cloud seeding does enhance rainfall in Tasmania under certain weather conditions. However, owing to the limitations in available observing technology in the 1970s, the physical evidence to support the statistical evidence is somewhat limited. The randomised trial with dry ice (DICSE) provided inconclusive results. It indicated a smaller increase in rainfall and the increase was not at an acceptably significant level. All subsequent seeding has been in operational mode with AgI as the seeding agent.

Our review on the Tasmanian experience with cloud seeding includes the scientific studies mentioned in the table below.

Study*	**Lead author(s) at**	**Experiment(s) analysed**	**Results**
Smith et al (1979)	CSIRO	Exp I	Increase in autumn rainfall of 30% in Central Plateau East and 9% in target west during seeded time units of 10 to 18 days. Significant effects too for Central Plateau West in winter and target east in summer.
Shaw et al (1984)	CSIRO	Exp II	Significant increase in rainfall in Central Plateau West, especially on westerly wind days. Increase in rainfall is 2.44 mm per day and 3.15 mm per day on westerly wind days.
Searle & Nebel (1998)	HEC	Exp I, II, Drought Relief (DR) & III (Dry Ice)	Exp I: Overall 19% increase in rainfall per seeded day; +30% autumn rainfall and 12% winter rainfall per seeded time unit Exp II: + 3.7 mm per seeded day or 36% increase total target area at 97% probability DR: based on percent normal analysis so results less reliable Exp III: regression analysis using dummy regressor variable; double ratio analysis
Pook & Budd (2002)	CSIRO	Exp I, II & III Desktop review of existing studies	See previous studies
Shaw (2002)	Antarctic CRC	Comments on Pook & Budd; Exp I, II & III	Comments on Pook & Budd

* see full description in bibliography and overview of study's content in literature review

Studies addressing the results of Experiment I and II indicate for autumn up to 30% increase in rainfall during seeded time units. Winter rainfall increased by approximately 12% per seeded time unit. Overall, the early studies indicate rainfall during seeded time units increases by 19% on average.

Overall the Tasmania II results seem to be more robust and the conditions of seeding in Tasmania II more nearly reflect more recent operational practice. Within the papers analysing the results of Tasmania II, two different statistical approaches (double ratio analysis and regression analysis) yielded statistically consistent results in that the individual estimates lie within each other's confidence limits.

The 'best estimate' of the cloud seeding effect was that there was a seasonal increase of about 116 mm of rain for the areas monitored in the Target West catchment (western part of the central plateau) during the experiment. Compared to indicative rainfall of 1300-1400 mm in the seeding season on the Western Central Plateau, this would represent a **maximum** likely increase of between 8% and 9% over average normal rainfall during the seeding season.

Evidence is consistent with cloud seeding effects being multiplicative. That is, seeding tends to increase rainfall by a particular proportion, not a fixed amount. Thus it may be reasonable to transfer the proportional increase to other affected areas.

For example, while the confidence of estimates in the Eastern Central Plateau (Target East) is weaker, such estimates as have been made suggest a similar proportional response in a slightly lower rainfall area.

No specific (published) estimates have been made of the effect of cloud seeding on rainfall in the two target catchments nearest to communities in the West Coast, Upper Pieman and King. We note however that these catchments, but particularly King, are among the least targeted by Hydro Tasmania, having fewer suitable seeding days. (Actual seeding frequencies are discussed in detail in the next section). As a result, while the increase in rainfall *per seeded day* may be in the same proportion, the seasonal increase in these target areas will be less because they have fewer seeded days each year. In addition, in general the West coast communities are outside of the target catchments, or on the very edge. As a result, these communities can be expected to receive a smaller increase than the target overall, even if targeting is not highly accurate.

Thus we proposed to adopt 8% as the highest likely seasonal effect on rainfall in the West Coast communities on the edge of or just outside the target catchments (Tullah, Queenstown and Rosebery).

Attempts to assess the effectiveness of recent seeding are limited by the lack of random unseeded periods. Without this, seeded periods will have an inherent bias to include months that would be wetter anyway. Under operational seeding, non-seeded months are those that were not seeded due to operational or mechanical problems related to the aircraft, or when seeding conditions were not satisfied for the whole month. The effect is therefore possibly overestimating the effects of cloud seeding unless double-ratios are used.

Most authors underline the importance of re-applying randomisation schemes into future cloud seeding operations if valid measures of effectiveness are to be obtained. This enables one to conduct a truly randomised double ratio analysis to reduce any bias.

4.1 Operations 1998 to 2007

The current operational phase of seeding operations by Hydro Tasmania commenced in September 1998. Initially, Hydro Tasmania intended to implement this phase as an experimental seeding program including a randomisation scheme, which is required for optimal statistical evaluation. However, due to drought and decreasing storage levels in its dams, Hydro Tasmania decided to transform the seeding program into an operational one, seeding on any suitable occasion and not allowing for suitable but unseeded events (randomisation scheme). The scope of this trial is larger than previous trials in that the Mersey Forth and Upper Pieman catchments are included in the listed target areas.

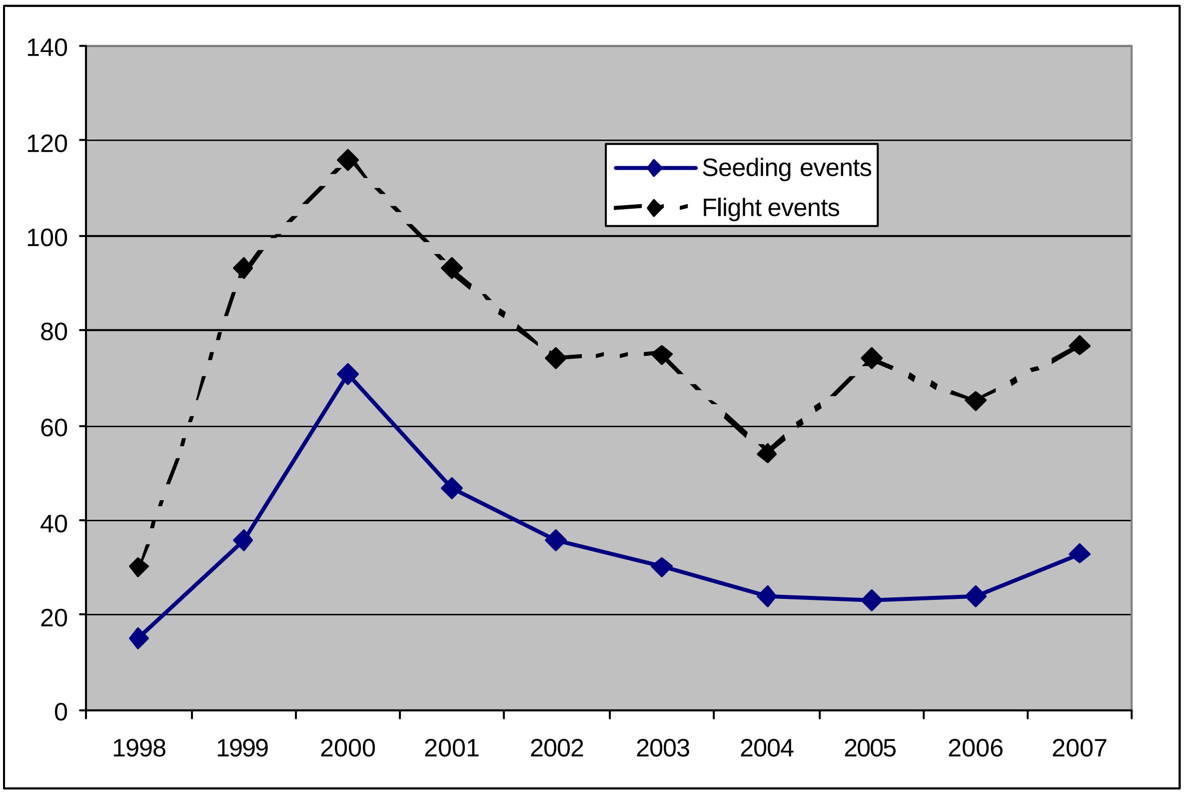
What makes the current phase of cloud seeding (since 1998) truly operational is the fact that the seeding program lacks any randomisation scheme. The current scheme does not incorporate any suitable days that are not seeded, making the preferred double ratio analysis not applicable. Manton mentions that Hydro Tasmania's current mode of operation makes it impossible to know if cloud seeding has an impact. The longer Hydro Tasmania continues this mode, the less likely an analysis based on historical rainfall levels will be valid in future. Shaw (2002) also underwrites the importance of applying randomised unseeded days in future operational phases of cloud seeding to sophisticate future research, as do Bigg & Turton (1998). It is generally agreed that better understanding can only be obtained from more comprehensive physical observations of the cloud processes assumed to be causing the rainfall enhancement.

Since the start of the program in 1998 until the end of November 2007 Hydro Tasmania's flight logbook[15] shows 751 flights were conducted. On 337 occasions the Cloud Seeding Officer (CSO) decided to perform cloud seeding activities. In total this led to 506 hours of seeding. If during flights no seeding was undertaken the conditions were regarded as unsuitable or it was merely a test flight (without any seeding).

In 1998 the seeding operations occurred in September and October only. During these two months there were 30 flights that included 15 seeding events, resulting in 21 hours of seeding. In subsequent years seeding operations were usually performed from April to November. The figure below shows the number of flights and seeding events per annum. Figure 15 below shows the total hours of seeding per annum.

[15] The logbook records are kept up to date by the cloud seeding officer (CSO) responsible for the flight recorded. Apart from this logbook, the pilot of the plane holds his/her own logbook which is required by law and for insurance purposes.

Figure 15. Annual flights and actual seeding events, 1998-2007



* in 1998 seeding events were limited to September and October only

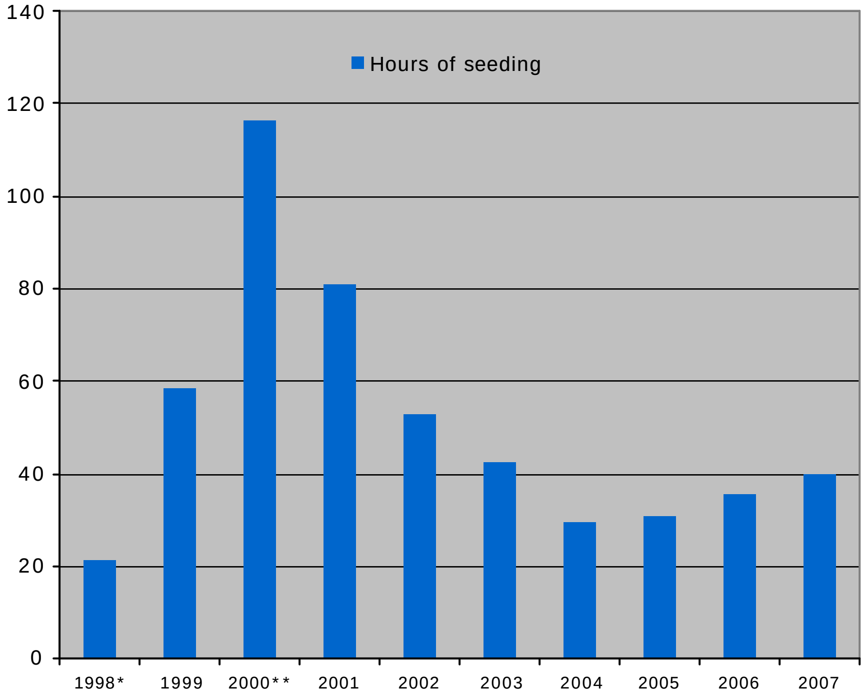
** 2000 included seeding events for drought relief in the midlands and the east coast

Source: Hydro Tasmania cloud seeding flight logbook, 1998-2007

The year 2000 shows exceptional seeding activity. During that year, seeding operations included a drought relief program aimed to reduce drought experienced by Tasmanian farmers and graziers in the midlands. In 2000 Hydro Tasmania conducted 117 flights during which seeding operations were conducted 71 times. During 18 events the flights targeted the area for drought relief. Nine events were solely aimed at drought relief and 9 events also targeted some of Hydro Tasmania's catchment areas. In total there were 116 hours of seeding. In 2000 Hydro Tasmania started 24 hour operations so more events were captured. This was not sustainable in 2001 due to staff turnover and a shift in emphasis to training where priority was given to day time events.

Figure 16 shows the amount of seeding was especially high during the first years of the program (1999 to 2002) and gradually decreased to a somewhat stable level from 2004 and onwards.

Figure 16. Annual hours of seeding, 1998-2007



* in 1998 seeding events were limited to September and October only

** 2000 included seeding events for drought relief in the midlands and the east coast

Source: Hydro Tasmania cloud seeding flight logbook, 1998-2007

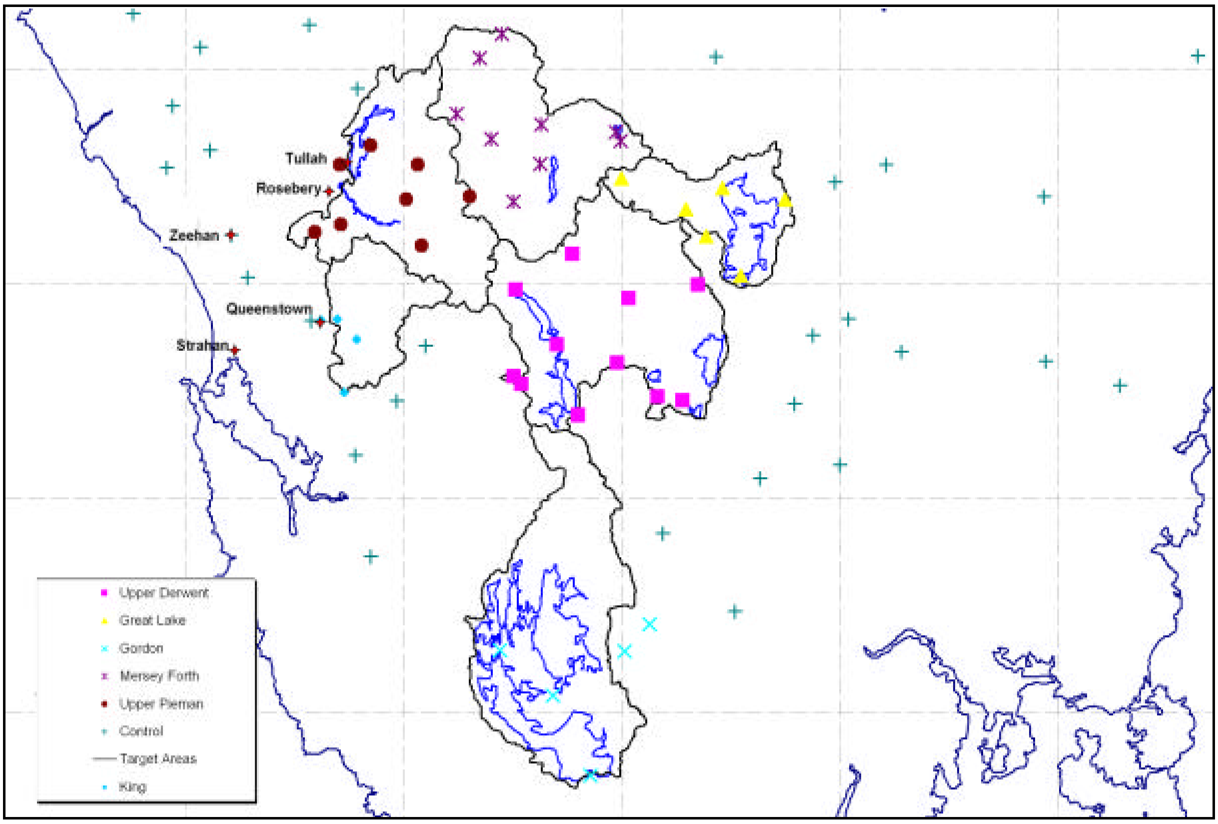
On average[16] Hydro Tasmania has conducted 76 flights per annum and seeding has occurred 31 times per annum. This results in 47 hours of seeding per annum on average.

An important feature of the program is that the number of suitable days for seeding per year is correlated with annual water inflows. That is, the wetter the year, the more seeding opportunities there are, and vice-versa. Dry years provide poor seeding opportunities hence good water management requires raising storage levels in wetter years (with assistance from cloud seeding) to compensate for storage drawdown in drier years.

The main target areas for seeding operations, drought relief not included, are Gordon, Great Lake, King, Mersey Forth, Upper Derwent and Upper Pieman (see map Figure 17 below).

[16] 1998, 2000 and 2007 excluded

Figure 17. Map of target areas Hydro Tasmania, 2004-2007



Source: Hydro Tasmania (2007)

Most seeding events target more than one area. Most frequently targeted is the Gordon catchment followed by Upper Derwent and Upper Pieman. Great Lake, Mersey Forth and King are seeded less frequently (see Table 4).

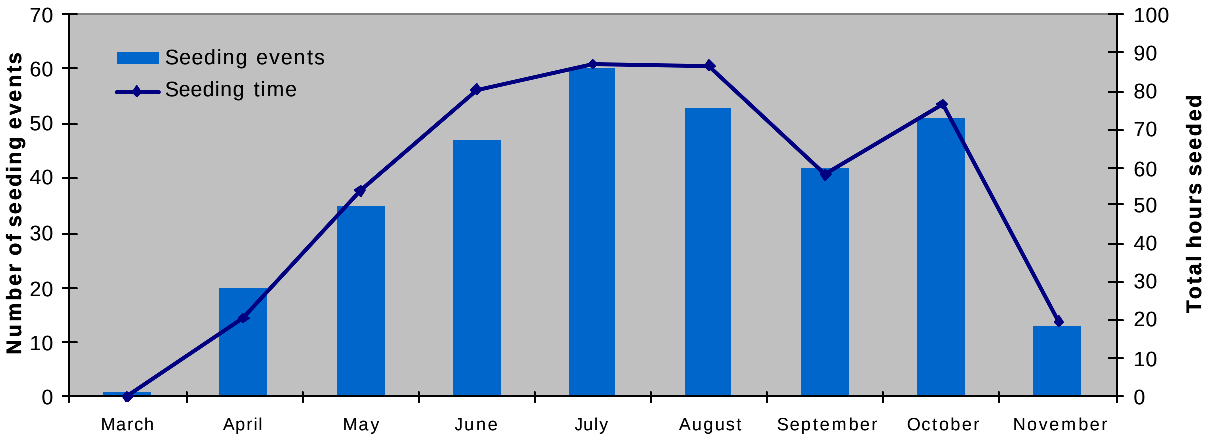
Table 4. Targeting of seeding events, 1998-2007

	Seeding events per catchment									
Targeted catchment area	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Gordon (Go)	1		30	14	16	18	14	13	18	14
Great Lake (GL) (or Target East)		5	27	22	23	13	6	5	5	5
King (K)	2		11	15	1	1		4	3	6
Mersey Forth (MF)	9	7	18	25	4	3	3	3	6	8
Upper Derwent (UD) (Target West)		5	31	26	23	1	2	7	6	13
Upper Pieman (UP)	9	9	16	21	4	3	5	9	6	9
Not specified	3	21	3	1	1		2			
Other (drought relief, etc.)		1	18							
Total seeding days	15	36	71	47	36	29	24	23	24	32

Source: Hydro Tasmania cloud seeding flight logbook, 1998-2007; many seeding events target more than one catchment

Seeding activities take place from April to November. The intensity of seeding operations shows a specific peak during the winter months July and August (Figure 18). On average there are four seeding events per month and the average total seeding duration per month is seven hours. In total, there have been 54 seeding events in July and 50 events in August between 1999 and 2006. These events add up to 81 hours of seeding in July and 82 hours in August months. During an average July month Hydro Tasmania conducted 7 seeding events and seeded for nearly 10 hours. An average August month is seeded approximately 6 times for just over 10 hours in total.

Figure 18. Monthly seeding operations, events and hours of seeding, 1999-2007



Source: Hydro Tasmania cloud seeding flight logbook, 1998-2007

The least amount of seeding activities take place in April and November. From 1999 to 2007 there have been 20 seeding events in April that account for 21 hours of seeding in total. There have been 2.5 seeding events per average April month. Since 2003 seeding activities during April have nearly ceased as there were only 3 seeding events from 2004 to 2007 which accounted for three quarters of an hour of seeding in total.

Seeding during November months has appeared even less frequently. From 1999 to 2007 there have been 13 seeding events during November months. These events added up to 20 hours of seeding. The November month in 2006 was quite heavily seeded: 4 events that accounted for nearly 8 hours of seeding.

Detailed overviews of seeding activities during specific years and months are in Appendix B.

4.2 Issues and recurring discussions on cloud seeding

Since the beginning of the current operational phase of cloud seeding on the Central Plateau in 1998 much has been said in regard to cloud seeding and the implications of it. Certain issues seem to reoccur in media articles on a regular basis without being resolved. This section aims to discuss these specific issues and to provide a substantiated answer based on data and views expressed by scientists.

4.2.1 Rain deprivation of downwind areas

The issue

In Tasmania there is concern about the effects cloud seeding may have on downwind areas to the east. Some believe the seeding on the Central Plateau deprives downwind areas from much needed rain. Consultation with community representatives and economic stakeholders reveals many residents of the West Coast expressed the same worries: "Why seed here while there already is sufficient rainfall and take rainfall away from the farmers who are already short of water?"
These concerns are not restricted to Tasmania alone. The issue has been discussed and analysed by several scientists in relation to various seeding experiments around the world.

What is *known* about the issue?

Firstly it is important to understand the physical process of evaporation and rainfall. Searle in this regard comments on the website of Snowy Hydro (2007): "A common misconception regarding cloud seeding is to consider the atmosphere a static pool of cloud water passing over the earth, which is a limited steady state supply of water. With this conceptual model, it very easy to argue that because this supply is limited and we remove a percentage of the water in the form of precipitation from the atmosphere through cloud seeding in one area, there will be less available to fall at other (downwind) locations because a larger fraction of this fixed supply of water was removed in another (upwind) location. Fortunately, the atmosphere does not behave in this simplistic manner. Clouds are systems that continuously process moist air. They are created when tiny water droplets form when cooling rising air ascends.

Precipitation data from a number of cloud seeding projects in the USA[17] have been examined in detail for evidence of external area effects. There are no statistically significant indications of rainfall/snowfall decreases downwind from any long term cloud seeding projects (Snowy Hydro website, 2007)."

"The mountains modify the clouds whether or not cloud seeding is in progress so that the clouds evaporate in the down-drafts in the lee of the ranges and rain or snow forming processes that were active on the windward side are terminated. These "downwind" regions receive their most useful rains when the winds are other than westerly (Searle, 2004; website Snowy Hydro)."

It is worth noting that most of the moisture in the air at a given time does not fall locally as precipitation. That is, the precipitation efficiency of most clouds is not high, and so most of the moisture continues to be transported through the atmosphere from one location to another. A water molecule will tend to stay in the air for about a week from the time it evaporates from the surface until the time it falls as rain.

[17] Study in Utah: Solak et al (2003), Estimations of downwind cloud seeding effects in Utah, North American Weather Consultants, Inc. Sandy, Utah, U.S.A.

Long (1998, on behalf of HEC, 1998) indicates some research has been undertaken to assess the downwind effects. Downwind effects potentially increase or decrease rainfall in downwind areas: a study in the USA (1973) found strong evidence of positive downwind effects at long distances (up to 250 km) and little evidence for decreases in precipitation downwind. Long mentions the available information is not adequate to apply the results to the Tasmanian topographic setting or particular set of meteorological conditions.

Searle and Nebel (1998) confirm that it is possible that cloud seeding may lead to increased or reduced rainfall in downwind areas. This is especially true for areas with a relatively uniform topography, which is not valid for Tasmania[18].

Pook and Budd mention that previous studies did not establish significant evidence of downwind effects. They refer to Ryan and King (1997) who note that it is statistically not possible to detect small effects, either positive or negative (Pook & Budd, 2002). Again, this is due to the high natural variability of rainfall between the upwind and downwind areas.

In regard to downwind effects it should also be noted that rainfall variability in the East and the West of Tasmania correlate weakly with each other. In other words, rainfall patterns in both areas are importantly influenced by separate weather systems.

Conclusion

There is no evidence cloud seeding operations over the Central Plateau deprive the Midlands or the East Coast of rainfall. First, clouds should not be seen as static objects moving from one place to the other. Second, international research so far has not been able to establish significant evidence of rain deprivation. Some evidence is available that says cloud seeding may actually increase rainfall in downwind areas depending on the specific topographic and climatic characteristics of the area (which are not applicable to Tasmania). Third, rainfall on the West Coast results from weather conditions that are not comparable to the conditions associated with rainfall in the Midlands and the East Coast.

4.2.2 Persistence effects of cloud seeding

The issue

Some early mainland cloud seeding experiments noted decreasing effects of cloud seeding over time (Long, 1998; Ryan & King, 1998). Some studies even returned negative effects where rainfall in control areas exceeded rainfall in target areas. This led Keith Bigg, to believe there are delayed effects of seeding.

What is *known* about the issue?

Bigg states that many previous studies on cloud seeding may have resulted in underestimations of the actual effects of cloud seeding (Bigg & Turton, 1998). Other experts agree that if persistence effects exist some previous experiments may underestimate the effects of cloud seeding (Searle &

[18] The Chinese government proposes to induce rain in clouds upwind of the Olympics opening ceremonies to reduce rainfall in Beijing and attempts at law suits to claim damage from cloud seeding arising from 'cloud rustling' in the United States.

Nebel, 1998; Ryan & King, 1998; Long, 1998). However, no conclusive scientific evidence is available to totally reject or totally accept the existence of persistence effects. Moreover, there is little evidence based on physical observations (Ryan & King, 1998).

It is argued by Bigg and some other scientists that somehow secondary ice nuclei are generated and then become airborne, generating additional rain up to thirty days after the seeding event (Bigg & Turton, 1988). Long wrote a review on previous studies of persistence effects on behalf of Hydro Tasmania. He mentions that studies into persistence effects have been going on for 40 years and returned mixed results. Long states persistent effects may last for hours or two days[19] and are limited broadly to the targeted area (Long, 1998). Attempting to prove or falsify the existence of persistence effects is problematic because of, just as is the case in assessing the effects of cloud seeding, the high natural variability of rainfall (Bigg & Turton, 1988).

In the discussion of cloud seeding effects in Tasmania and the West Coast most of the persistence effects (if any) are incorporated in the analysis because of the broad time frame attributed to 'seeded period' in some leading studies; eg. Searle & Nebel (1998) and Smith et al (1979).

In fact, after the early mainland experiments (1955-63) CSIRO adjusted the design of the experiments. The first experiment applying this design was the first Tasmanian experiment (1964-71):

- the experiment used control areas that were not seeded on any occasion;
- the time window of 'seeded period' was on average twelve days thereby largely 'absorbing' delayed effects of at least several days and;
- each year with seeding operations was followed by a year without seeding operations.

Based on this information, there is no reason to assume the rainfall effects of cloud seeding in the West Coast are higher than claimed in various scientific studies in Tasmania.

Conclusion

There seems to be some evidence of persistence effects due to cloud seeding. However, the evidence is not conclusive: a) studies conducted in the area have returned mixed results, b) establishing statistical evidence is difficult because of the high natural variability of rainfall and c) there is insufficient understanding of the physical process that would explain the phenomenon.

In regard to this study it is important to note it is very unlikely the rainfall effects of cloud seeding in Tasmania are underestimated (assuming there are persistence effects). The time units used in most analyses are wide enough to account for these effects. Also, analysis of the second experiment with 'suitable day' as time unit returned results of a similar magnitude.

4.2.3 The environmental impacts of cloud seeding

The issue

[19] After two days the effects decay significantly (Long, 1998).

On several occasions media articles expressed serious doubts about the environmental and health effects of cloud seeding. These worries were also expressed during consultation with community representatives and economic stakeholders on the West Coast. Hydro Tasmania has always indicated there are no adverse environmental impacts and the quantities of seeding agent used are too small to have any negative consequences. A recent article mentioned there may be some adverse environmental impacts of cloud seeding by Snowy Hydro's operations (NSW). However, no evidence was provided to substantiate the claims and Snowy Hydro has rejected the claims.

What is *known* about the issue?

Since the first cloud seeding experiments some environmental impact assessments have been carried out both internationally and nationally. So far, none of these studies have identified any significant adverse environmental impacts due to cloud seeding or the use of silver iodide as seeding agent.

Hydro Tasmania (HEC, 1998) too has carried out an environmental impact assessment[20]. The EIA partly consists of a literature review. It also includes three expert reports on:

a) the impacts of silver iodide as a seeding agent;
b) the existence of persistence effects, and;
c) the downwind effects of cloud seeding (see previous section).

The report on the impacts of silver iodide concludes there are no adverse impacts on the environment from the silver iodide that was expected to be released as part of the program[21]. The conclusions in regard to silver iodide indicate that the amount of silver iodide dispersed during cloud seeding operations is small compared to naturally occurring amounts of silver. The estimated concentrations in seeded rainfall are well below maximum standards for silver iodide in freshwater and are therefore considered safe.

Further, silver iodide tends to bind easily with particles in the soil, chloride ions and clay minerals.

> *Most of the silver lost to the environment each year enters terrestrial ecosystems where it is immobilized in the form of minerals, metal, or alloys.*[22]

As a highly mineralised region, it is anticipated that the West Coast would have local areas with naturally occurring significantly higher than average concentrations of silver than anything arising from cloud seeding operations.

Iodine is a non-toxic element and the release of it through cloud seeding operations is not considered to have any environmental impacts (HEC, 1998; Dick, 1998). In fact iodine in the form of iodide is deficient in Tasmania's soils and is added as a supplement to some foods. According to the Better Health Channel, a Victorian Government website:

[20] In accordance with Hydro Tasmania Environmental Management System (EMS). There was no legal requirement for Hydro Tasmania to perform this assessment.

[21] At the time (1998) the program was aimed to be experimental. However, since then Hydro has decided to change it into an operational phase which does not include 'suitable unseeded periods'.

[22] Environmental Contaminants Encyclopedia Silver Entry, National Park Service, Water Resources Divisions, Water Operations Branch, 1201 Oakridge Drive, Suite 250, Fort Collins, Colorado 80525

> *If you don't have enough iodine in your diet, it can lead to an enlarged thyroid gland (goitre) or other iodine deficiency disorders. Iodine deficiency is the world's leading cause of mental retardation in children.*[23]

Prior to operations beginning, Searle and Nebel (1998) estimated that on an annual basis up to 50 kg may be dispersed and at worst, 25kg will reach the ground in the target area. In practice the most AgI used was in 2000, approximately 32kg (due to highest number of seeding hours due to drought relief seeding). Hydro Tasmania has used 6-10 kg of silver iodide per year since 2004 when application rates were lowered.

The amount reaching the ground in the target areas amounts to a few grams per square kilometre per year. The maximum permissible safe level of silver in water is 1,000 times greater than that found in rainwater from seeded clouds (Searle & Nebel, 1998). Therefore they conclude there is no real threat from silver iodide in the study area and off-site effects are extremely unlikely.

Conclusion

There is no scientific evidence nationally and internationally that shows there are significant adverse environmental effects of cloud seeding and of silver iodide as a seeding agent. Silver iodide is used at very low doses and is non-toxic.

4.2.4 Extreme rainfall events due to cloud seeding

The issue

Consultation with community representatives and economic stakeholders on the West Coast reveals many parties believe cloud seeding operations alter the characteristics of rainfall: they indicate raindrops are larger, rainfall is heavier and rainfall is more enduring than 'normal rainfall'. West Coast Council indicates in the past extreme rainfall events have led to land slides and flooding and it believes cloud seeding has contributed to this on several occasions.

What is *known* about the issue?

Cloud seeding operations are undertaken if conditions are deemed suitable. Suitable conditions occur if the chance of rainfall is high, the wind is in a direction so that orographic uplift occurs and wind speed is not too high. Seeding during (thunder)storms is therefore usually avoided due to high wind speeds and due to a lack of suitable conditions for seeding.

Cloud seeding is based on the assumption that a basically-stable cloud system can be triggered to become more efficient in the production of rainfall. The impacts of cloud seeding are generally incremental. On the other hand, severe weather systems are highly organised such that there is strong feedback between their structure and the production of rainfall. It is therefore unlikely that the conditions laid down for cloud seeding would be met during a severe weather event.

[23] http://www.betterhealth.vic.gov.au/BHCV2/bhcArticles.nsf/pages/Iodine_explained?OpenDocument

The BoM indicates extreme rainfall events occur primarily due to (thunder)storms. Comparison of dates of extreme rainfall events with cloud seeding operations may give an indication of the relationship between extreme rainfall events and cloud seeding.

BoM keeps records of daily rainfall. SGS requested BoM to provide data on the rainfall and dates of the 40 most extreme rainfall events in Queenstown (South Queenstown gauge) from 1997 to October 2007, and 31[24] most extreme events in Rosebery from September 1997 to October 2007, as defined by total rainfall in a 24 hour period.

It should be noted, the results can not be interpreted as scientifically conclusive evidence: Whenever there were no seeding events just before an extreme rainfall event it is fair to conclude cloud seeding did not exacerbate rainfall, resulting in torrential rain. However, whenever there were seeding operations on the day of an extreme rainfall event[25] it is fair to state it is that seeding *may* have contributed to it, but it is not *proven*. Seeding usually occurs if the conditions are deemed suitable; in case of predicted high rainfall but no storm activity, there is a good chance Hydro Tasmania will decide to seed.

For Queenstown the data reveal that 8 out of the 40 wettest days (20%) occurred in the 21 months (18% of the period) before cloud seeding began. Of the remaining 32 out of 40 wettest days that occurred in the time spanning the current phase of operational seeding (September 1998 to October 2007), 12 (38%) occurred in the months December to March when cloud seeding does not take place.

There was only one rainfall event that that coincided with seeding opera tions targeting the King catchment, or 1 of 32 (3%) of the wettest days between September 1998 and October 2007 were preceded by a seeding operation targeting the adjacent King catchment.

This event occurred *during the 24 hours to 9 am* of 31 October 2001. Total rainfall reached 50 mm and that day is the 20th wettest day between 1997 and 2007. A flight on 30 October targeted the King catchment, along with four other areas (CP[26], Mersey Forth, Upper Pieman and Gordon) and seeding continued for 1 hour and 25 minutes.

The correlation between extreme rainfall events and seeding operations seems to be very weak for Queenstown. BoM indicated they believe most extreme rainfall events occur during thunderstorms. As will be noted in the next section, Hydro Tasmania procedures state seeding operations are suspended in case of high wind speeds and flood warnings. Furthermore, Hydro Tasmania indicates the King catchment is of marginal importance and seeding operations target this area infrequently.

[24] 9 events between 1988 and 1993 were left out of the selection; the measurements related to a different gauge and do not occur within the current seeding phase.

[25] Manton comments to this: Given the lack of evidence of persistence and the fact that extreme events tend to occur in different synoptic conditions from those in which seeding is carried out, the only valid analysis is to look at days on which seeding occurred and a severe event occurred later that day.

[26] CP (Central Plateau) was specified on the log which refers to the Upper Derwent.

For Rosebery there were 28 extreme rainfall events between September 1998 (start of current operational seeding program) and October 2007. Seven of these (25% of extreme events) occurred in the non-seeding summer period. Rosebery is adjacent to the Upper Pieman catchment. The Upper Pieman is a more frequently targeted catchment area than the King.

During that period there were four extreme rainfall events that coincided with seeding operations targeting the Upper Pieman. These four events were *the 24 hours to 9 am on*:

- 18 August 2001. Total rainfall was 44 mm. A flight on August 17 targeted Upper Pieman and Mersey Forth. Seeding continued for 2 hours and 41 minutes;
- 31 October 2001. Total rainfall reached 44 mm. A flight occurred on October 30 targeted Upper Pieman and other catchments. Seeding continued for 1 hour and 25 minutes;
- 1 June 2003. Total rainfall reached 42 mm. A flight on May 31 targeted the Upper Pieman together with Mersey Forth, King and Gordon. Seeding continued for 1 hour and 34 minutes;
- 25 July 2003. Total rainfall reached 53 mm. A flight targeted the Upper Pieman and Mersey Forth on 24 July 2003 and seeding operations continued for 1 hour and 2 minutes.

Thus four of the 28 wettest days at Rosebery, or 14%, coincided with seeding operations targeting the Upper Pieman. This amounts to about one event every two years in which seeding coincided with extremely heavy rain. However there were 5 wetter days with rainfall from 54 to 104 mm that occurred on non-seeded days during the same period, the wettest two events being in summer (non-seeding period). While there seems to be some correlation between high rainfall events and seeding operations, seeding operations are undertaken if there is a good chance of rainfall anyway which will bias the relationship.

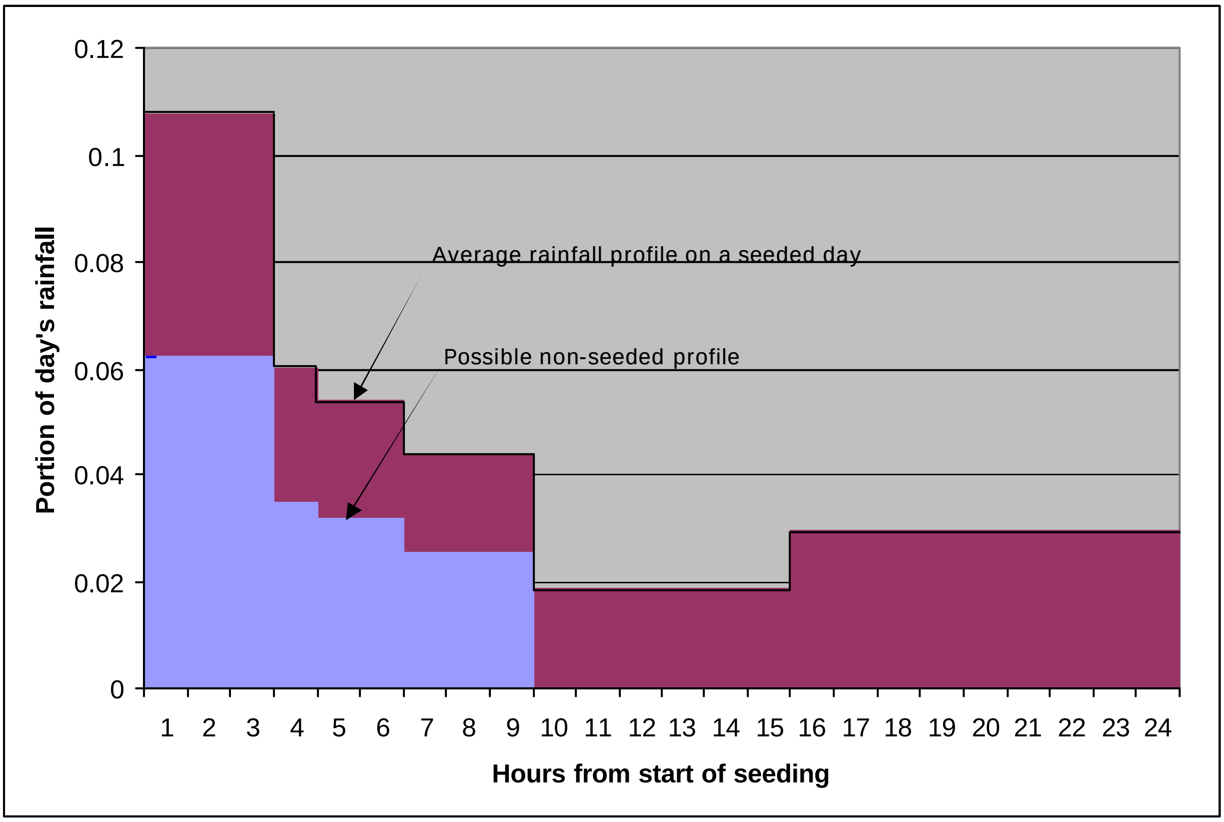
The above analysis focuses on rainfall within a 24 hour timeframe and does not consider enduring (more than 24 hours) heavy rainfall. It also does not reflect shorter 'bursts' of heavier rain that do not lead to extreme rainfall over the 24 hour period. Most analysis of rainfall has focussed on the overall impact on rainfall received, not daily or hourly effects. However, we can deduce a limited amount from considering what evidence does exist.

Overall, increases in rainfall on a seeded day are expected to be of the order of 30% to 40% compared to a comparable unseeded day. An increase of 30% to 40% in rainfall intensity is unlikely to be evident to an observer without the aid of instruments. However, the impact of seeding is expected to be relatively short lived, and applies to only part of the seeded day.

The distribution of rainfall on seeded days was presented by Shaw et (1984) Figure 6 in that report. The data are redrawn in Figure 19 below. It is seen that about 60% of the day's rainfall occurs in the 9 hours following the commencement of seeding. If we assume that the effects of seeding are confined to that 9-hr period and that the effects of seeding on the days total rainfall is an increase from un-seeded rainfall of 35%, then the rainfall over the nine hour period must increase by about 70% above the 'natural' level for the nine hours.

The distribution of rainfall on unseeded days with respect to the preferred seeding time has not been studied so the profile of unseeded rainfall is necessarily speculative. However, this does suggest that increases in rainfall intensity immediately following seeding **may** be noticeable, even if the overall increase for the day of say, 35% is not readily apparent due to high levels of variability.

Figure 19. Possible short term rainfall effects of cloud seeding



Conclusion

The Bureau of Meteorology observes that severe weather events tend to occur under special meteorological conditions. It is found that seeding has occasionally occurred on the days of a severe precipitation event. The above analysis shows there is only very weak evidence of correlation between cloud seeding operations and extreme rainfall events in Queenstown. There is evidence of cloud seeding operations coinciding with extreme rainfall in Rosebery. However, there is no proof of a causal relationship. Seeding operations are undertaken if there is a good chance of rainfall anyway.

Seeding may cause short periods of noticeably more intense rainfall, although this effect has not been specifically studied.

4.2.5 Flooding as a result of cloud seeding

The issue

West Coast Council indicates Strahan is occasionally subject to floods and the Council believes at least some of these floodings are due to cloud seeding operations. Hydro Tasmania suspends seeding operations in case of flood risks and indicates it does not believe their seeding operations have contributed to any flood events.

What is *known* about the issue?
The referee at Hydro Tasmania determines when and where cloud seeding operations may take place. Key aspects for making these decisions are the water levels in the individual catchments and expected flood risks. For determining the flood risks the referee refers to BoM's flood warning services. Cloud seeding activities are suspended if Moderate to Major Flood warnings are brought out in regard to rivers in target areaor in a downwind catchment area adjacent to target area. The planned seeding track is to be adjusted if Moderate to Major Flood warnings are valid in upwind catchment area adjacent to target area; it is rescheduled either to the boundary with the adjacent catchment in flood, or inside the cloud seeding target area (Hydro Tasmania, 2003).

BoM manager Hydrology Services indicates flood warnings for the West Coast are predominantly based on rainfall forecasts. For the West Coast BoM provides a generalised service based on basic modelling. Factors such as soil condition, tidal effects and existing river flows are not taken into account for the flood warnings. Although rainfall is generally acknowledged as a factor causing floods, these other factors play a role in determining the effect of rainfall, or in the case of tidal effects, independently of rainfall. Because the flood warnings for the West Coast are generalised and based on rainfall forecasts predominantly, there is a chance the warnings are inaccurate.

Consultation with State Emergency Services (SES) NW Region (regional manager B. Dubton) revealed that initially flooding on the West Coast was not seen as an issue compared to other areas that are known to be prone to flood risks. However, flood risks in Strahan have recently been re-assessed and the manager confirms some low parts of Strahan (near Manuka Creek) are prone to some minor flood risks. He also indicates most flood events are due to tidal effects and the state of existing buildings and infrastructure in the low lying areas of Strahan. The only flooding that is known to be caused by rainfall occurred on 28 June 2004. No seeding took place on that day or the day before. Seeding took place in the Gordon catchment on 26 June (37 minutes) and on 23 June in the Upper Pieman (1 hour).

Conclusion
In case of flood risks the referee will stop seeding operations or modify the seeding route such that seeding does not affect the risk area. The flood risk warnings are produced by BoM. BoM indicates the warnings for the West Coast are predominantly based on rainfall forecasts and do not include soil conditions, tidal effects and existing river flows. Due to these procedures it is possible flood risks may exist without being noticed by BoM.

Since rainfall is hardly recognised as the key factor causing flooding in Strahan (it is mainly due to tidal effects and current storm water management), and no seeding coincided with flooding associated with rainfall, it is not plausible to conclude cloud seeding has so far caused flood events, nor is there reason to assume it will do so in the future. However, seeding may have the potential to make the flooding worse if BoM's flood warning system fails to notice flood risks due to tidal or other factors.

4.2.6 Unintended seeding effects within West Coast

The issue

One of the most crucial debates concentrates around the issue of unintended rainfall effects outside Hydro Tasmania's targeted areas but within the communities of the West Coast. Both Queenstown and Rosebery are at the border of Hydro Tasmania's catchment areas.

What is *known* about the issue?

Seeding takes place 30 minutes upwind from the catchment boundary[27]. The 30-minute upwind guideline represents a simple application of the understanding of precipitation physics. Between 2002 and 2005 the aircraft seeded 74% of the time to the west, northwest or southwest of target and 15% of the time the aircraft is more than 50km upwind of the target to the west, northwest or southwest (pers communication Morrison, 2007).

Alex Nazarov (Hydro Tasmania) observes the 30 minute guideline seems to work well in practice but no supporting evidence was provided. He agrees that the higher the wind speed the less accurate the targeting becomes, and seeding does not occur if the wind speeds are too high.

Mike Manton indicates that it takes at least 30 minutes for seeding material to lead to rainfall on the ground. In earlier experiments, CSIRO used 30 minutes for cumulus and 45 minutes for stratiform clouds. Hence the consistent use of 30 minutes will reduce the chance of any inadvertent upwind impacts.

In most modern experiments, targeting is aided by the use of dispersion models that use available meteorological data to predict the dispersion of cloud seeding material. Dispersion modelling may provide more accurate targeting and reduce unintended rainfall outside target areas.

Various scientific studies in the impacts of cloud seeding in Tasmania conclude it is effective for enhancing precipitation. Most studies include control areas at significant distance from the target area to ensure no unintended seeding effects 'contaminate' the analysis.

A recent analysis by Morrison provides some evidence of unintended seeding effects in a buffer zone around the target area. The analysis included a modification of the western part of the target area by expanding it by 25 km to the west and reclassifying 9 out of 18 rain gauges from 'west control area' to 'target area'. The results indicate that more months experience significant effects of cloud seeding than before the reclassification and confirm unintended seeding does affect parts of the (original) control west, which includes Rosebery and Tullah (Morrison, pers comm). Mike Manton indicates the results do suggest the existence of unintended seeding effects but that there is insufficient evidence to confirm the magnitude of these effects.

[27] The guideline was revised by Alex Long in the late 1990s. Given the size of catchments seeded this is not much different from the old guideline of 1hr upwind of target centre for winds lighter than about 30kt. Under high wind conditions this guideline places seeding operations closer to the catchment area than the previous guideline of the Stage II trial.

Conclusion

There is some evidence that suggests unintended seeding takes place in the area adjacent to the Upper Pieman target area and affects rainfall. Rosebery and Tullah lie within this area. The evidence is inconclusive and does not quantify the magnitude of the unintended rainfall.

4.2.7 Night time cloud seeding

The issue

Many west coast residents have believe that cloud seeding occurs primarily or exclusively at night and have expressed concern about this.

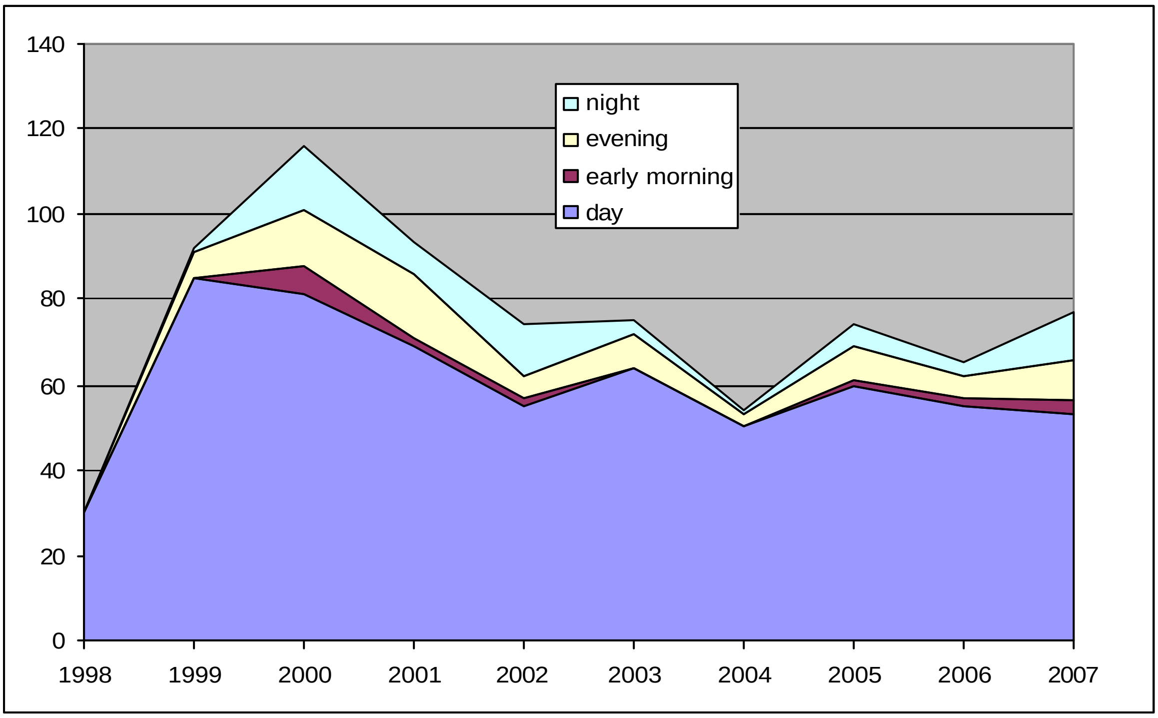
What is known about the issue

In general, cloud seeing is scheduled when it is expected that it will be effective. In practical terms, with night time seeding it is more difficult to make some of the observations that confirm that seeding is likely to be effective. Figure 20 shows the pattern of flights by time of day, with all flight assigned to one of four categories:

- **Day** – flight took off after 6:00 am and landed before 6:00 pm
- **Evening** – flight took off before 6:00 pm but landed after 6:00 pm
- **Night** – flight took off after 6:00 pm and landed before 6:00 am
- **Early** morning – flight took off before 6:00 am and landed after 6:00 am.

The average length of a flight is 2 hours and 30 minutes.

Figure 20. Time of day of flights, 1998-2007



Source: flight log books

SGS Economics & Planning

On average, 80% of flights occur during the day. Only 8% of flights occur at night, with 12% in the early morning or evening. As a proportion of all flights, night flights were highest in 2000, 2002 and 2007.

When non-day time operations have occurred, they usually correspond to an opportunity to seed that has not occurred during daytime hours. This is shown by the proportion of flights seeded by the time of day of flight in Table 5 below.

Table 5. Proportion of flights in which seeding occurred by time of day of flight

Time of day	% flights seeded
day	42%
evening	63%
night	50%
early morning	71%
All flights	**45%**

However, it is expensive to keep operational crews available 24 hours per day so to the extent that there is limit on the total hours of operation, day times are generally preferred.

Conclusion

Night flights do occur but they represent a small minority of all seeding flights. When they occur it is because the seeding conditions are favourable and have not been at other times of day.

4.2.8 Notification of cloud seeding

The issue

Many West Coast residents have requested that they be given prior notice of cloud seeding operations so they can plan activities to avoid rainy days. They have expressed concern that they are always only informed ‘after the fact’.

What is known about the issue

The decision to fly is based on weather forecasts and developing weather conditions that may change hourly. As soon as the situation is judged favourable for seeding, a flight will take to the air. Lead times from decision to fly until take-off are a few hours at most.

However, not all flights result in cloud seeding. Once airborne the CSO assesses the conditions in the sky before seeding begins. Less than half of all flights result in cloud seeding.

Cloud seeding is targeted. Each flight that seeds targets a particular catchment, or if conditions are suitable, several, one after the other. Just as the decision to seed is made on the basis of conditions at the time, so also is the decision as to which catchments to seed.

Once seeding begins, it begins producing any effects after 30-45 minutes. Flights continue for up to 2½ hours, although seeding times are usually about 1½ hours. The seeding time reflects the length of time that clouds are suitable for seeding. Seeding usually continues as long as suitable conditions continue, or until the plane needs to land to refuel.

Conclusion

Seeding is not scheduled in advance so it is impossible to give more than one or two hours notice. At best it may be possible to report that a flight or seeding is in progress once it commences.

5 Conclusions

Statistical analysis of cloud seeding in Tasmania have produced scientific relevant results indicating cloud seeding does enhance rainfall in target areas compared to control areas. Overall, the statistical design of Experiment I and II was of a good quality, enabling scientists to draw significant conclusions.

However, it should be noted that all analysis of cloud seeding effects is influenced by the high natural variability of rainfall, which makes it impossible for unaided human observation to discern the effects of cloud seeding, except possible for short term increases in intensity. Complex statistical analysis is necessary to establish evidence of the longer term effects of seeding. High variability and limited numbers of observations / data only enable scientists to observe relatively large rainfall effects. Roughly speaking it takes at least 100 seeded days to detect rainfall effects of say 10% or more. Given proper design including randomisation schemes and suitable but unseeded days, a maximum of 20 seeded days in an average year, it would take 5 years of experimenting to achieve this.

5.1 Effects of cloud seeding

Collating various studies on cloud seeding in Tasmania, the conclusion is that cloud seeding is effective and that precipitation is enhanced by up to 8% per ‘seeded’ month in the target areas.

In Tasmania cloud seeding is particularly effective in case of stratus clouds containing sufficient cold water droplets, during westerly winds and while the clouds undergo orographic uplift. Cloud seeding does not lead to more rainy days but to more intense rainy days. Cloud seeding does not create clouds, but only enhances precipitation from clouds.

5.2 Cloud seeding operations

Cloud seeding is undertaken if Hydro Tasmania’s dams are beneath optimal storage levels. Hydro Tasmania states it only targets those dams that need water. The targeting of cloud seeding operations follows the guideline that seeding from the plane takes place 30 minutes upwind from the area’s boundary.

Conditions are continually monitored to determine likelihood for suitable conditions (temperature, cloud presence, cloud levels, liquid water concentration, winds – speed and direction etc). This is done from the ground with the aid of weather forecasts, satellite images, computer models, etc. Should there be potentially suitable conditions the CSO flies to evaluate conditions in situ. If conditions are found to be suitable seeding occurs. Conditions are continually monitored from the aircraft and seeding continues only as long as conditions are suitable. If conditions deteriorate a new target area is explored or the flight is called to end. Operations are suspended (by an internal referee) in case of flooding or if dams are near or on spill.

The current operational phase of cloud seeding commenced in September 1998 and continues to present. Cloud seeding operations are undertaken from April to November. There are fewer flights during April and November (approximately 2 seeding events per month), while July through to October are the most intensely seeded months (approximately 5.5 events per month). On average Hydro Tasmania conducts four seeding operations per month. The number of flights is roughly twice as high because during the flights it often becomes clear conditions are not/no longer suitable for seeding.

The most common target area is Gordon, which is not near any of the townships of the West Coast. Other areas that are targeted frequently during seeding flights are Upper Derwent and Upper Pieman. The latter is close to Rosebery and Tullah. Rosebery is located west from the area and Tullah is located within the area. The King catchment which is targeted the least of all areas is next to Queenstown. Strahan and Zeehan are both further away from the catchment areas and are not mountainous areas where clouds may undergo orographic uplift. Macquarie Harbour is an area where several of the rivers and streams from the catchments flow. Floods and high tides occasionally affect Strahan. While rainfall contributes to flood risks in Strahan, tidal effects and existing storm water infrastructure are seen as key factors causing floods. BoM's current flood warning system for Strahan is not completely 'watertight'. BoM is revising the system and is considering taking tidal effects into account.

A recurring issue associated with cloud seeding operations is the lack of any randomisation in the seeding strategy. This strategy means that Hydro Tasmania and the community have no reliable information on the impacts of cloud seeding on rainfall in the region since the 1980s. Owing to the large natural variability of rainfall in the region and to the possible impacts of climate change, a randomisation strategy will be required if any improved information is to be available about effectiveness and impacts. However, given the past evidence showing effectiveness and the current practice of seeding every suitable day, the introduction of randomised non-seeded days will represent a loss of rainfall and its value in terms of power production. Further, as a randomised trial would need to continue for an extended period to provide good information, that loss could be substantial. The benefits in terms of reduced operating cost or greater future effectiveness would have to be sufficient to warrant this loss, an outcome that is highly uncertain.

Another recurring issue arises from the operational targeting strategy, which relates directly to the potential for inadvertent seeding effects outside the target area. While the current targeting strategy appears to be conservative, it does not use available modelling technology to adjust the seeding location to variables such as cloud base and the level at which seeding occurs, as well as the impact of the local topography on trajectories. It would therefore be appropriate to consider the use of a modern dispersion model to estimate the actual trajectories of seeding material. There is some evidence that suggests unintended seeding occurs in an area which includes Rosebery and Queenstown. There are insufficient data to estimate the magnitude of these effects.

The scientific review reveals there may be some evidence of persistence effects, but the evidence is inconclusive. However, even if there are persistence effects lasting up to several days, the statistical analysis it is highly unlikely to underestimate the effects cloud seeding.

Furthermore, there is evidence showing extreme rainfall events (4) in Rosebery have coincided with cloud seeding operations. These were not the most extreme events for Rosebery. However, there is no proof of a causal relationship. Seeding operations are undertaken if there is a high probability of rainfall anyway.

There is no scientific evidence that shows cloud seeding operations deprive the eastern half of Tasmania of rainfall. And to conclude, there is no evidence of adverse environmental and health effects of the seeding agent silver iodide.

5.3 Minimum and maximum effects of cloud seeding on the West Coast

To assess the 'real' and perceived economic and social impacts it is crucial to make clear what the likely effects of cloud seeding are in terms of rainfall and rainy days. For some possible economic effects, such as tourism, it is important to know what effect cloud seeding has on the **number of rainy days** whereas in regard to flood damage the **rainfall amounts** would be most significant.

Hydro Tasmania does not cloud seed on fine sunny days, nor on days that are unlikely to rain anyway. We expect that the increase in the number of rain days over the West Coast LGA and Hydro Tasmania storage catchment areas due to cloud seeding to be zero.

The magnitude of the effects of cloud seeding is still regarded as uncertain by most scientists. However, there are some clear indications of the range within which these effects lie. To assess the economic and social impacts this minimum-maximum range will be important. The ranges as described below are based on the results presented in previous sections.

There is some evidence that suggests some unintended seeding occurs outside the targeted areas. Queenstown, Rosebery and Tullah are most prone to these effects. The maximum effect of cloud seeding in these townships would be the 8% increase in monthly rainfall **for seeded months**.

In addition, there is evidence that shows seeding occurred on a day during which extreme rainfall was recorded. This is particularly true for Rosebery. In regard to the maximum range it is therefore assumed that in Tullah and Rosebery seeding is expected to contribute to at most 1 extreme rainfall event every two years (on average). Queenstown may experience such an event once in approximately 10 years. Consequently, Strahan could potentially be affected by flooding through King River at most once a decade too (only in regard to the maximum range).

At the minimum end of the scale the effects of cloud seeding are assumed to be negligible in townships outside target areas. Scientific evidence so far does not produce any <u>substantial</u> evidence of unintended seeding outside the targeted areas. The evidence provided is not more than suggestive. If there are no outside target area effects then there should be no effects of cloud seeding in Queenstown, Rosebery, Zeehan and Strahan. Tullah however, is an exception in this regard. The township is located within the Upper Pieman target area. Therefore, even in terms of minimum effects, Tullah is expected to be affected by cloud seeding. In regard to the minimum range it is estimated rainfall effects in Tullah account for 4% increase in monthly rainfall for seeded months. Four percent is well within natural variability of monthly rainfall.

Rainfall in Zeehan is not likely to be affected by cloud seeding at all; it is well upwind from any target area and is not mountainous. Furthermore, the township is not known to be prone to flooding as a consequence of excessive rainfall. Therefore, our 'best estimate' is that cloud seeding does not affect Zeehan at all.

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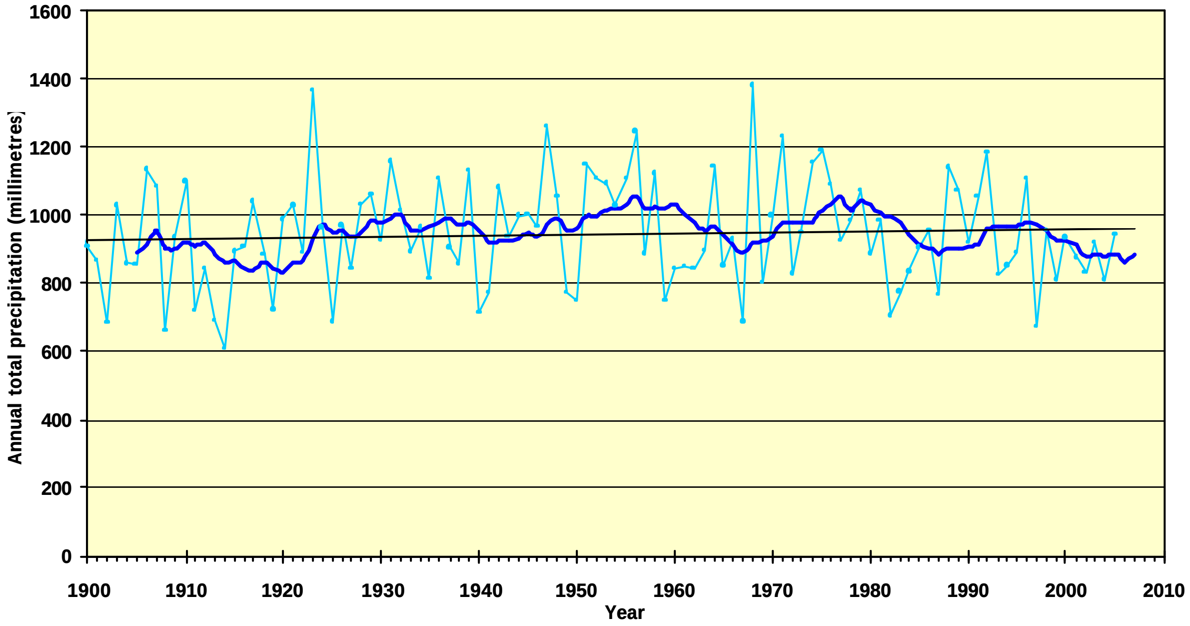
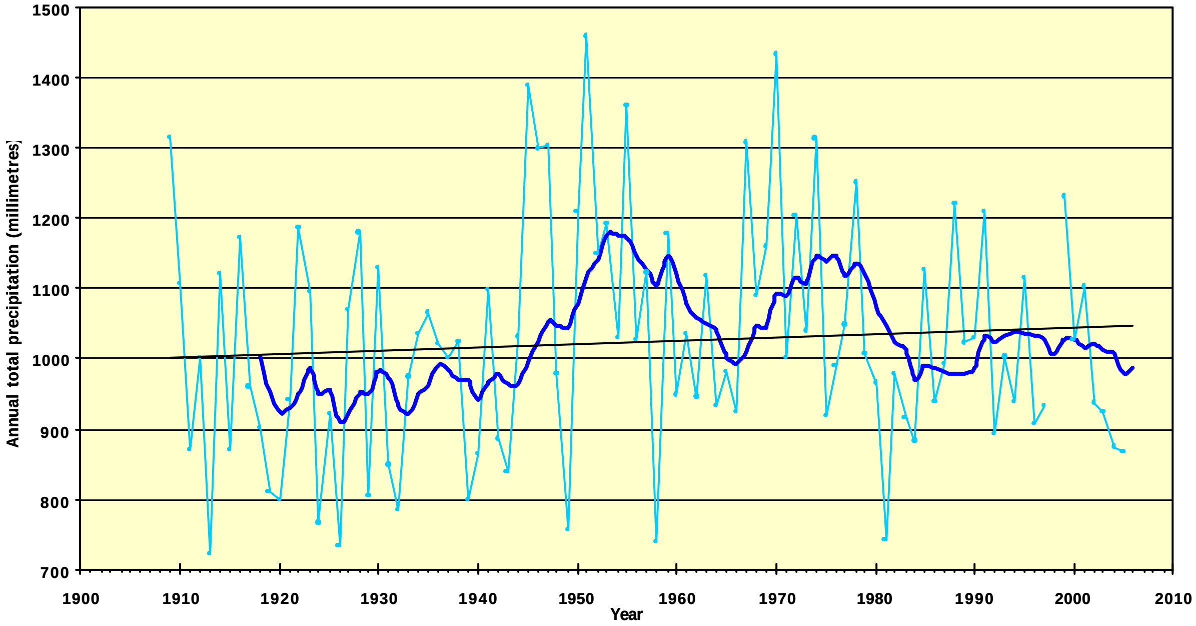
Appendix A Long term annual rainfall at reference sites

Figure 21. Annual total precipitation in Cape Grim, 1906-2006



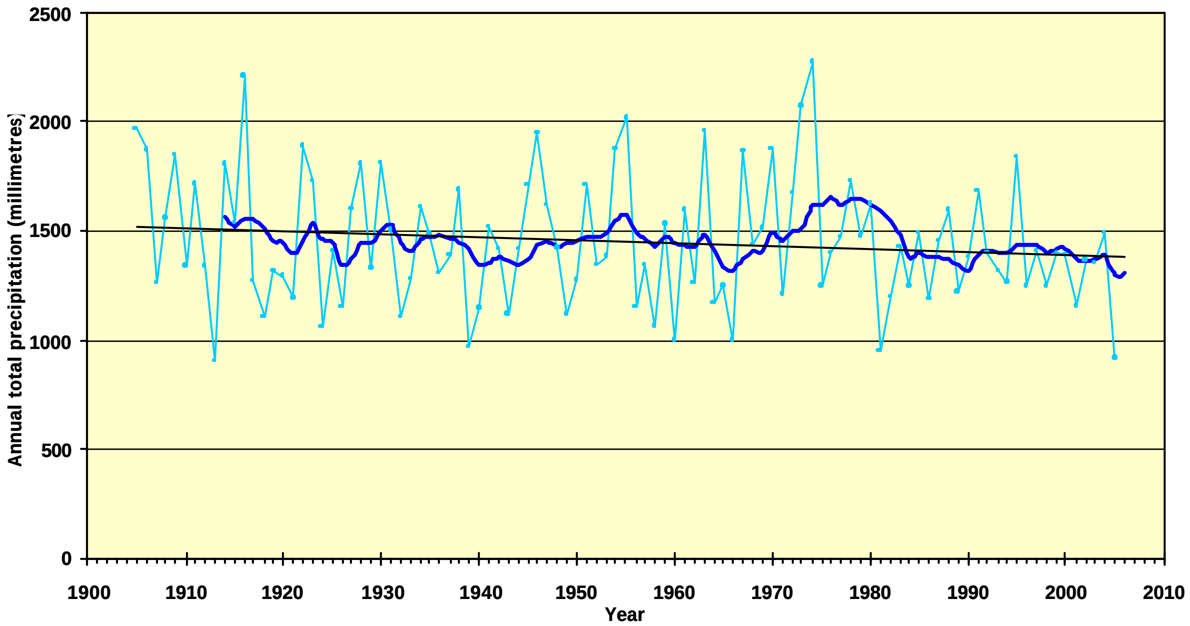
Source: BoM (2007)

Figure 22. Annual total precipitation in City of Melbourne Bay (King Island), 1906-2006



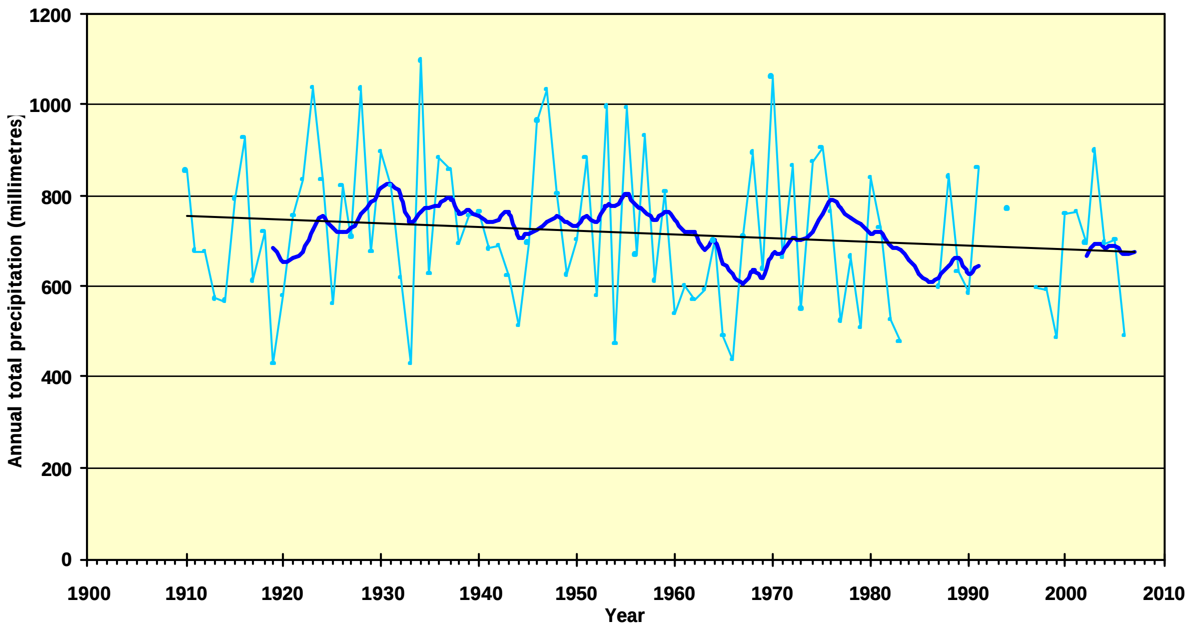
Source: BoM (2007)

Figure 23. Annual total precipitation in Yolla, 1906-2006



Source: BoM (2007)

Figure 24. Annual total precipitation in Osterley, 1906-2006



Source: BoM (2007)

Appendix B overview of seeding operation 1998-2007

Overview seeding operations 1998-2007					
		Data			
year	year/month	Sum of Seeding Event (0=0 & 1=yes)	Sum of Seeding time	Count of Flight No.	Average duration of seeding
1998	September	7	9	16	1.4
	October	8	12	14	1.4
1998 Total		15	21	30	1.4
1999	April	0		2	
	May	2	6	16	2.8
	June	6	8	11	1.3
	July	12	17	18	1.5
	August	6	8	11	1.3
	September	0		13	
	October	9	17	16	1.9
	November	1	2	6	2.2
1999 Total		36	58	93	1.6
2000	March	1	0	3	0.1
	April	9	9	13	1.0
	May	6	8	13	1.4
	June	7	14	12	1.9
	July	11	20	18	1.8
	August	13	23	17	1.8
	September	12	22	20	1.9
	October	11	20	15	1.8
	November	1	0	6	0.3
2000 Total		71	116	117	1.6
2001	April	4	8	15	2.0
	May	1	1	5	1.5
	June	10	16	16	1.6
	July	5	12	8	2.3
	August	12	23	14	1.9
	September	6	8	9	1.3
	October	7	11	16	1.6
	November	2	2	11	1.2
2001 Total		47	81	94	1.7
2002	April	1	0	6	-
	May	1	3	3	3.0
	June	9	20	17	2.2
	July	4	6	8	1.5
	August	5	6	15	1.2
	September	6	6	9	1.1
	October	8	8	11	1.0
	November	2	4	5	1.9

Year	Month	Count of Seeding Events	Sum of Seeding time	Count of Flight No.	Average duration of seeding
2002 Total		36	52.8	74	1.5
2003	March	0		1	
	April	3	2.7	11	0.9
	May	3	6.7	9	2.2
	June	1	0.8	10	0.8
	July	3	5.0	8	1.7
	August	4	5.2	9	1.3
	September	8	8.8	13	1.1
	October	7	12.1	11	1.7
	November	0	0.9	3	
2003 Total		29	42.1	75	1.5
2004	April	2	0.1	5	0.0
	May	7	7.5	12	1.1
	June	6	9.9	11	1.7
	July	2	3.5	5	1.8
	August	3	2.8	5	0.9
	September	2	4.7	5	2.3
	October	1	0.5	7	0.5
	November	1	0.4	4	0.4
2004 Total		24	29.4	54	1.2
2005	April	1	0.6	7	0.6
	May	1	2.1	4	2.1
	June	1	1.3	11	1.3
	July	11	14.4	19	1.3
	August	5	10.3	10	2.1
	September	1	0.2	11	0.2
	October	1	0.1	4	0.1
	November	2	1.7	8	0.9
2005 Total		23	30.8	74	1.3
2006	April	0		8	
	May	6	8.8	12	1.5
	June	2	4.6	6	2.3
	July	6	3.5	12	0.6
	August	2	4.3	7	2.2
	September	3	5.0	9	1.7
	October	1	1.3	7	1.3
	November	4	7.7	4	1.9
2006 Total		24	35.2	65	1.5
2007	April	0	0.0	10	
	May	8	10.5	12	1.3
	June	5	6.6	9	1.3
	July	6	6.0	14	1.0
	August	3	4.4	9	1.5
	September	4	3.7	10	0.9
	October	6	8.3	11	1.4
	November	0	0.0	2	
2007 Total		32	39.6	77	1.2
Grand Total		337	506.3	753	1.5
Average		4	7	10	1.4
Median		4	6	10	1.4

	Seeding Events per month by year									
year	March	April	May	June	July	August	September	October	November	Total
1998							7	8		15
1999		0	2	6	12	6	0	9	1	36
2000	1	9	6	7	11	13	12	11	1	71
2001		4	1	10	5	12	6	7	2	47
2002		1	1	9	4	5	6	8	2	36
2003	0	3	3	1	3	4	8	7	0	29
2004		2	7	6	2	3	2	1	1	24
2005		1	1	1	11	5	1	1	2	23
2006		0	6	2	6	2	3	1	4	24
2007		0	8	5	6	3	4	6	0	32
Total	1	20	35	47	60	53	49	59	13	327

Appendix C Literature review

(see bibliography for overview)

Name of document	**Bigg, E.K. & Turton, E. (1988)**, *Persistent Effects of Cloud Seeding with Silver Iodide*, In: Journal of Applied Meteorology, Vol. 27, p. 505-514, May 1988.
Year of document	1984
Location	Australia
Overview of the document	Statistical analysis of precipitation records in and around cloud seeding areas suggest there are delayed effects of seeding. As a result, statistical analysis of cloud seeding so far may have resulted in underestimations of the actual effects of cloud seeding. Secondary ice nuclei are expected to be involved with the persistent effects of seeding. If this is so, the effectiveness of cloud seeing may be higher than so far assumed (i.e.: although some studies have been designed to account for these effects, at least to certain degree). There is little physical evidence of a persistence effect presented.
Method	Superposition method using data from all Australian experiments, to determine whether rainfall on days after seeding was statistically significant higher than before and/or than after unheeded (but suitable) days. Control areas are always chosen so that their precipitation correlates well with the target when seeding is absent. In the real world this correlation is never perfect due to seasonal trends, (semi-)periodicies that appear differently in target and control. A double ratio largely excludes these aspects; therefore double ratio superposition is applied. This security measure also makes it harder to detect small cloud seeding effects ("even in the best experiments, it has taken more than a hundred seeded days to detect with any confidence, a 10% increase due to seeding"). The same is true for detecting persistent effects.
Findings	• In the early days of cloud seeding several scientists reported of observations that concentrations of ice nuclei remained high for considerable periods after seeding (Grant, 1963; Bowen, 1966; Rosinski, 1966; Bigg, 1985; Bigg & Turton, 1986). As possible explanation Rosinski mentioned the productions of secondary ice nuclei. Some physical experiments have been conducted to assess whether persistent effects could occur and produced some successful results too; • Attempting to proof or falsify the existence of persistent effects is problematic because of –as is the main issue in assessing cloud seeding effects in general- the noisiness (natural variability) of rainfall which makes it hard to detect small effects. This paper aims to overcome the issue by combining the results of all previous Australian experiments; • 7 Australian experiments were included: 3 of them using target and unseeded controls (Snowy Hydro and twice Tasmania), and all three returned positive, significant results. None of the 4 cross-over experiments showed significant rainfall increases; • Each seeded area of the crossover experiments was treated as a separate experiment and new controls were established for each. Moreover, suitable unseeded days were defined based on having similar distributions of rainfall amounts so they were likely to be meteorologically similar. Unseeded days were selected from unseeded years, and some adjustments were applied to minimise annual climatic differences; • The superposition functions S(d) and U(d) were calculated for 'd' in the range 31 days before to 31 after the seeding or non-seeding (but suitable) event; • "We believe that the use of a huge number of seeded days (1245), 11 different experiments, the multiplicity of controls, and double ratios using unseeded suitable days, makes the probability very slight of a significant difference occurring in the two halves of a superposition function spanning 60 days, unless its cause has some physical basis related to seeding." • The results show a sudden increase of rainfall (fluctuations) from before the seeding days (day -30 to 0) to days of seeding and the 30 days thereafter (days 0 to 30); • The mean rainfall in the period after seeding is 17.7 s (standard deviations) higher than the mean rainfall in the period before seeding! "Consequently, we are either dealing with a very large spurious signal, or an overwhelming significant physical phenomenon. • To assess the likelihood of 'a very large spurious signal', first the authors determined that the observed signal was due to rainfall in seeded and following days (as apposed to unseeded and following days). Then they compared summer and winter results (as seasonally related changes would be the most likely cause for a spurious signal) and concluded season was not causing it. Then they showed the differences in mean rainfall 'after' compared to 'before' seeding per control area and per season in number of s. The results show that rainfall after seeding is higher than before seeding; • **The authors therefore conclude that the data make it improbable that anything but a real**

	physical phenomenon is involved. • The analysis presented does not give indications of the nature of the effect (physical phenomenon), but previous physical experiments make it seem reasonable that secondary ice nuclei are generated and then later on become airborne; • Moreover, the analysis suggests that secondary ice nuclei must be more effective than AgI in enhancing precipitation. Hence, there must be better ways of seeding (better agents) than current practices; • Evidence against persistent effects only consists of the fact that there are insufficient data per experiment that consequently produce inconclusive results, and should not be seen as evidence of absence; • The authors know of no contrary evidence other than the apparent improbability that delayed effects should occur. • Analysis based on historical records may experience difficulties emanating from climatic shifts but would avoid problems that have occurred in previous studies.
Limitations	• Inconclusive evidence of the physical phenomenon at work. • No independent analysis of historical data by other scientists

Name of document	**HEC (1998)**, *Cloud Seeding. Environmental Impact Assessment.* The Tasmanian area cloud seeding experiment Stage 4. By: Environmental Services Consulting Business Unit, HEC. File ref: 7033. For: Systems Division, HEC, December 1998
Year of document	1998
Location	Tasmania, CS Experiment Stage IV
Overview of the document	Environmental impact assessment (EIA) for the fourth stage of Tasmanian Cloud Seeding in accordance with Hydro Tasmania's Environmental Management System (EMS).
Method	EIA, partly literature review and partly based on 3 expert reports on: a) effects of silver iodide *(Dick, C. (1998), Effects of Silver-Iodide: Assessment of Environmental Impacts,* on behalf of Hydro-Electric Corporation), b) persistent effects of cloud seeding (Long, A.B. (1998), *Persistent Cloud Seeding Effects*, on behalf of Hydro-Electric Corporation), and c) downwind effects of cloud seeding (Long, A.B. (1998), *Downwind Effects of Precipitation Enhancement*, on behalf of Hydro-Electric Corporation)
Findings	• Apart from intended and clearly identified benefits of cloud seeding (see other reviews) the EIA identified some potential adverse impacts. Some are relevant in regard to this project and are outlined below (effects of increased rainfall, persistent effects and effects of flooding); • Murchison/Upper Pieman Catchment target area (close to Tullah and Rosebery) and its three power stations comprise 15.6% of Tasmania's power generating capacity; • King Catchment (adjacent to Queenstown) is a relatively small catchment area of 560km2 • Residents within the target area will be largely unaware of seeding operations as the additional rainfall is generally within the range of natural variability (see question, point seems weakly substantiated) • Silver iodide: overall, there are no adverse impacts on the environment from the silver iodide that was expected to be released as part of the experimental phase IV program. Dick concludes that a) the number of particulates released for cloud seeding is very small compared to natural and other pollution sources. The particulates will not reach the surface in detectable amounts and will not cause damage to human or animal lungs. The effects of the particulates in solar radiation will be negligible; b) the amount of silver iodide dispersed during cloud seeding operations is small compared to naturally occurring amounts of silver. The estimated concentrations are well below maximum standards for silver iodide in freshwater and are therefore considered safe. Further, silver iodide tends to bind easily with particles in the soil, chloride ions and clay minerals. C) Iodine is a non-toxic element and the release of it through cloud seeding operations is not considered to have any environmental impacts. • Studies into persistence effects have been going on for 40 years and returned mixed results. There is evidence persistence effects occur and that their duration extends to approximately two days and thereafter effectiveness decays significantly; • Persistence means cloud seeding may affect the microphysical structure of clouds and the development of precipitation for days after the seeding has been completed. • Persistence may complicate the evaluation of a cloud seeding experiment and reduce the perceived

	effect of the seeding. • There has been considerable post-analysis of precipitation data associated with persistent effects in Australia. There appears to be a flaw in some of the analysis which exaggerates the time span (said up to 2 weeks) of the effects. • Downwind effects: Long concludes there is scientific information available on downwind effects. However, this information is not adequate to infer whether downwind effects will occur in any given Tasmanian topographic setting or for a particular set of meteorological conditions. US research (1973) showed strong evidence of positive downwind effects at long distances and little evidence for decreases in precipitation downwind. More research is needed aimed at the physical process and at statistical verification and quantification of the effects. Long proposes a research program. • CS should not cause increased flooding as the operations are to be suspended at times of increased flood risk.
Limitations	• Mike Manton indicates 560km2 is a very small catchment.

Name of document	**Hydro Tasmania (2007)**, *WM-Instruction-P01/02 Meteorology, Monitoring, Interpretation of Weather Conditions and Flight Criteria*, last revision August 3, 2007
Year of document	2003, last revision 2007
Location	Tasmania
Overview of the document	Aim is twofold: one, to assist in a structured manner with the decision of whether to fly or not; and two, the collection of data for process analysis and improvement. Describes weather conditions conducive for cloud seeding and data sources the Cloud Seeding Officer (CSO) should consult. Typical meteorological conditions that are likely to generate conditions that are suitable for cloud seeding are cold fronts, low pressure surface troughs, low pressure centres located between the quadrants south west to north west of Tasmania, west to south westerly stream when the dew point temperature at Strahan is above 4°C, areas of convection or convergence generating cumulus cloud. Ideal cloud top temperatures to target are those in the –6° to –15°C range as indicated on infra red satellite images.
Method	n/a
Findings	Fly/No fly decision • For four parameters the stated criteria must at least be met in order to decide positive on the fly question: 1. Cloud Depth & Cloud Top Temperature (Cloud depth must be > 1/3 terrain clearance of base elevation; and cloud top temperature <= -6oC.), 2. Cloud Cover (Minimum acceptable cloud cover is cumulus > 3/8 or stratiform > 5/8). 3. Wind Vector (Wind direction must be in the 200-020 sector; wind strength must be < 70 knots). 4. Freezing Level (Freezing Level must be greater than 3,500' for ground height safety reasons (–6?C to –15?C is 3000' to 8000' above freezing level). • Other criterion is: 5. Atmospheric Stability/Instability • However, insight of CSO may be used to override decision. • The procedure also provides input to determine the upwind distance. For process improvement on long term CSO's need to fill out forms to upgrade monitoring and decision analysis in the long term. (Flight Log to be filled out after flight (xls) and Log Book to register observations during flight.
Limitations	• Process improvements depend on accurateness of CSO's in filling out forms

Name of document	**Hydro Tasmania (2003)**, *WM-Instruction-P01/04 Airborne Evaluation of Cloud Conditions*, last revision July 2003
Year of document	July 2003, last revision October 2003
Location	Tasmania
Overview of the document	Aim: description of the necessary steps to evaluate cloud conditions for cloud seeding suitability once airborne and steps to initiate cloud seeding.
Method	n/a

Findings	• It is only possible to classify a cloud as suitable or unsuitable for seeding during a flight as vital parameters are measured on location in cloud. Cloud Seeding Officers are therefore encouraged to initiate a flight if only to assess conditions to confirm them unsuitable. It can be surprising at times to find conditions contrary to expectations. • Activities to undertake: cloud monitoring, precise determination of wind speed and direction, define seeding track (take into account 30 minutes displacement, define length of seeding according to size target area and wind speed –length shorter if wind stronger-, and alignment), assess cloud according to minimum cloud suitability criteria, seed cloud (as long as condition are suitable, and time & supply available).
Limitations	•

Name of document	**Hydro Tasmania (2003)**, *WM-Instruction-P01/05 Adjusting to Changing Conditions*, last revision October 2003
Year of document	July 2003, last revision October 2003
Location	Tasmania
Overview of the document	Aim: description of the possible changes in conditions that affect cloud seeding and the actions a Cloud Seeding Officer has to take to adjust to changes. The atmosphere is an ever-changing environment, and at times it can change very quickly, particularly where wind speeds in excess of 50 knots occur. The CSO may be faced with the need to continually change the flight plan, sometimes changing it within minutes of having notified the pilot of intentions. Less obvious however, are the subtle changes to cloud, temperature and wind conditions that are always occurring. The CSO must be alert to these changes and compensate accordingly.
Method	n/a
Findings	See overview
Limitations	n/a

Name of document	**Hydro Tasmania (2003)**, *WM-Instruction-P01/07 Cloud Seeding Operation when Flood Warnings are in Place*, last revision October 2003
Year of document	July 2003, last revision October 2003
Location	Tasmania
Overview of the document	Aim: to provide guidelines for where cloud seeding operation may take place when the various levels of flood warning from the Bureau of Meteorology are in place.
Method	n/a
Findings	• The **referee** will monitor flood warnings and notify cloud seeding officers accordingly. Duty Cloud Seeding Officers are encouraged to also check the status of specific target area before seeding The referee: • Cloud seeding activities are suspended if Moderate to Major Flood warnings are valid in regard to rivers in target area. • Cloud seeding activities are suspended if Moderate to Major Flood warnings are valid in *downwind* catchment area adjacent to target area. • Seeding track is to be adjusted if Moderate to Major Flood warnings are valid in *upwind* catchment area adjacent to target area; reschedule to either on the boundary with the adjacent catchment in flood, or inside the cloud seeding target area. CSO on duty: • Act in accordance with the above guidelines • In addition it would be prudent for the duty cloud seeding officer to check the status of flood warnings before seeding target areas. A record of actual or potential opportunities lost due to the restrictions of this policy should be maintained in the

	cloud seeding group.
Limitations	n/a

Name of document	**Long, B.A. (1998)**, *Persistent Cloud Seeding Effects*, on behalf of Hydro Electric Corporation, contract B/200070, November 1998.
Year of document	1998
Location	Tasmania, as input to EIA CS experiment Phase IV
Overview of the document	Overview of extent of persistent effects of cloud seeding. The report has been used as input for the AEI for Phase IV of Hydro Tasmania's cloud seeding programs.
Method	
Findings	• Persistent effects may last for hours or days, but they apply to particular geographic areas and time periods. CS evaluation normally assumes effects occur 0.5-1hr after seeding. • Persistence of cloud seeding effects means that the microphysical structure of clouds and the development of precipitation continues for a significant amount of time (say days) after the seeding has been completed. • Persistence may complicate the evaluation of a cloud seeding experiment and reduce the perceived net effect of the seeding; the sensitivity of the experiment to 'observe' effects may be reduced. By reassigning the days following a seeding event as being part of the seeding event (instead of identifying them as unseeded days), one could include persistent effects correctly in the analysis. • The idea of persistence was developed after several experiments indicated decreased CS effects with time after recurring seeding operations in an area (both nationally and internationally); • There has been considerable post-analysis of precipitation data in Australia. Unfortunately, there appears to be a flaw in some (but not all) of the analysis which exaggerates the time span (said to be up to two weeks) of the effects. • Measuring and examining ice nucleus concentrations may be a worthwhile exercise in search for persistence effects. For some projects the concentrations appear to be elevated after seeded days for a period of a few days and thereafter they decay. • Bigg and others suggest AgI may be carried to the surface where the nuclei are believed to stimulate a chemical reaction and/or a biological process from which products are emitted into the atmosphere (and which subsequently create rain). • Apart from ice nucleus concentrations other conditions must prevail as well to make persistence possible (cloud formation, supercooled liquid water, excess liquid water over ice water and minimum cloud depth and area); • This article provides quite detailed background on the potential origin of persistent effects. In light of this study it is not considered relevant to discuss that in detail.
Comments	• Phase IV was intended as an experimental phase, but has become a fully operational program and does not include any randomisation schemes for statistical validation/analysis. • The term Phase IV is no longer used.

Name of document	**Pook, M.J. & Budd, W.F. (2002)**, *An Evaluation of Cloud Seeding Operations carried out in Tasmania by Hydro Tasmania. An Independent Report*. Prepared for Hydro Tasmania, DPIWE and Tasmanian Farmers and Graziers Association (TFGA).
Year of document	2002
Location	Tasmania
Overview of the document	A debate continues in scientific circles about the effectiveness of the process in producing rainfall enhancement that can be detected unambiguously above the background 'noise' of natural rainfall variability. Hydro Tasmania carried out two experiments on cloud seeding of which the results are assessed in this study. Experiment I extended from 1964 to 1971 and Experiment II from 1979 to 1983.
Method	First two methods are a) linear regression and b) double ratio analysis. A third method to analyse historical rainfall is percent of normal analysis.

<table>
<tr>
<td>Findings</td>
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Critical in assessing cloud seeding effects are detailed design of target and control areas, provision of adequate observation networks, randomisation of seeding trials and sophisticated statistical analysis of the results;
Ex I: per day clouds were assessed on basis of 'suitability criteria' and the decision to seed or not is made after applying a randomisation protocol. The exp was conducted in alternate years to prevent contamination by so-called persistence effects (Bigg, 1995; Long, 2001a). Pairs of periods of seeding/non-seeding of approx. 12 days ware applied. Significantly, no account was taken of what proportion of the rainfall recorded during a 'seeded period' fell when conditions were regarded as suitable for seeding, according to a predetermined definition.
Ex II. Experimental unit was reduced from 12 day periods to that of 'suitable day'. Each suitable day was then applied to a randomisation protocol. Target areas were same as in Exp I but introduced a system of floating <u>upwind</u> controls.
Climatology Tasmanian Rainfall Patterns: rainfall in Tasmania is determined by westerly airstreams and on the west coast it undergoes orographic lifting. Many other factors influence rain as well (cloud depth, temperature, humidity, atmospheric stability etc). Seasonal variations are affected by subtropical high pressure and circumpolar trough of low pressure from the Antarctic. The westerlies are strongest in spring and autumn. In winter west coast can be influenced by high pressure blocks from the north, reducing rainfall.
Over an approximately 100 year period there has been no discernible trend in winter rainfall at Cape Grim in the far northwest, a slight increase at Queenstown and a decreasing trend at Oatlands. The decade from 1991 to 2000 was particularly dry at Oatlands and the five-year mean winter rainfall centred on 1997 is similar to that of 90 years earlier (1906).
Rainfall data are derived from BoM stations and Hydro Tasmania gauges with complete data sets for 1944-2000.
Queenstown and Target West experienced higher rainfall in the 1990s probably due to westerly atmospheric circulation

Analysis Exp I

54 Seeded/unseeded pairs distribution is 12 pairs in autumn, 14 in winter, 16 in spring and 12 in summer
Smith et al (1979) conducted analysis. Their results were: good evidence on effects in target and effects vary with conditions.
Some changes were made to experimental conditions and these made analysis less consistent. Seeding time was much higher in second part of period.
Concerns in relation to choice of controls relates to some changes. Above that upwind locations / west of target area would have been more appropriate and was adopted in Exp II.

Analysis Exp II

New equipment and technology enabled a more strict definition of ´suitable day´. Analysis units were consequently set at days instead of longer periods. Also floating controls were introduced (westerly wind days selected only also westerly control areas). Only stratiform cloud types were included in experiment.
The stricter definition of suitable day resulted in a significant drop in number of suitable days for experimentation
The ratio seeded:unseeded days decreased from 1:1 to 2:1 compared to ExpI
Seeding significantly increases rainfall for selected suitable days and the average increase in rainfall was 2.44 mm per seeded day and 3.15mm for seeded days with westerly wind
Both regression and double ratio analysis yield significant positive effects in case of upwind control areas
Two basic assumptions under the analysis are a) seeding agent has no effect on control areas, and b) seeding has no persistence effect beyond 24 hrs
Long and Biggs contend there is evidence of persistence effects with AgI interacting in a biological process.
One of the author's main concerns throughout the article is the limited number of cases for analysis. However, statistical tests show significant relations and these tests take sample size into account. Sample size should therefore not be used as an argument to weaken the conclusions (on the contrary) / see more in review of Shaw (2002).
The authors reassessed the Exp II results and draw predominantly the same conclusion
Standard deviation is very large in the analysis that includes cumulus clouds. Hence, the authors´ analysis resulted in a non-significant effect. Much less is s in case of stratus clouds only. A significant and positive effect was established.
The authors emphasise the importance of westerly control areas.

Downwind effects:
</td>
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- Previous study (Smith et al, 1979; Shaw et al, 1984) concludes there are no significant downwind effects. However, Ryan and King (1997) note that current analysis does not allow detecting small effects. Authors conclude no significant downwind effects are discernable in data (which is a different conclusion!).

Historical analysis of cloud seeding:

- Percent normal analysis is used to compare rainfall in seeded periods to a long term mean or median rainfall. Previously carried out by Searle & Nebel (1998) and Bigg (1995). Searle & Nebel concluded 10-15% more rainfall in seeded months than unseeded months.
- Natural variability makes this type of analysis difficult
- Again upwind control area is stated desirable (not affected by seeding but with correlated rainfall patterns)
- Authors looked at mean and s rainfall for selected stations for period 1944-2000. Monthly rainfall is standardised to mean.
- A positive effect was established for winter and spring. But same result was seen in Queenstown. Their conclusion is –assuming no there is cloud seeding effect on Queenstown- that natural variability contributes strongly to effect.(but check Shaw's critique; there is some evidence seeding took place in relatively wet months)
- Limited quantity of suitable data is again blamed (which is a wrong conclusion – see Shaw; This type of analysis is not regarded as the right one)

Other influences on rainfall:

- El Nino-Southern Oscillation (ENSO) represents a swing in sea surface temperature (SST). Rainfall over eastern Australia is affected by it. In Tasmania only the north-eastern half is affected by it, and it is not significant for rainfall patterns in west and southwest.
- Antarctic circumpolar wave producing swings in SST. 8-10 year double cycle. So far effects from ACW are seen as limited.
- Inter-annual variability is much greater in Tasmania.
- Atmospheric circulation also plays a determining role, especially in regard to winter rainfall. Atmospheric blocking can reduce rainfall significantly (1989 low rainfalls on west coast)
- Authors underwrite conclusion by Shepherd (1995) that variability in East and West of Tasmania only correlate weakly; they are two separate systems.

Long-term trends:

- CSIRO projections indicate that Tasmania will become drier in all seasons except in winter. Winter rainfall is expected to increase by 20% to 2030 (*what is base year??)* For the west coast this might be even higher.

Conclusions per question:

Q1. Have Hydro Tasmania's cloud seeding experiments and statistical evaluations been conducted in a scientifically credible manner?

Authors state the experiments have been carried out in scientifically credible manner, apart from earlier mentioned critique.

Q2. What effect has cloud seeding had on rainfall in the target area?

Ryan and King (1997, p253) concluded that, "In Tasmania, there is strong statistical evidence for rainfall enhancement for (stratiform) clouds with cloud-top temperatures between –10° and –12° C in a south-westerly airstream." The studies of Smith et al. (1979) and Shaw et al. (1984) claimed significant increases in particular seasons or months. The authors conclude there is overall modest increase in rainfall in Stage I and a marked increase in Stage II (westerly winds and stratiform clouds), no conclusive result for the larger/unscoped data sets of Exp II.

Q 3. Have the cloud seeding experiments and operations produced significant extra-area effects (anywhere in Tasmania) on rainfall? If so where, of what kind (increase or decrease), and of what magnitude?

The authors state there is no evidence of significant influences of seeding operations outside the target area.

Q 4. Is there any statistically significant evidence that Hydro Tasmania's cloud seeding is impacting to reduce rainfall in Tasmanian agricultural areas?

Q5. Given the existing information and knowledge, could there be any other explanation for the perceived decline in rainfall in some agricultural areas of Tasmania?

Authors seem to answer a vaguely worded yes.

The authors have not detected any evidence of significant influences of seeding operations on agricultural areas in Tasmania. This is not surprising as correlations between rainfall in the Target Area and the main agricultural regions are not particularly high.

Some of the Recommendations:

The atmospheric processes that produce rainfall are complex and it will always be difficult to separate the contribution of natural processes and variability from human-induced effects. The authors therefore recommend that an effort be made to maintain a randomisation scheme within future operational cloud seeding programs.

	Additionally, they suggest periodic independent review of the data. The authors recommend a detailed study of long-term trends in Tasmanian rainfall.
Limitations	• See comments by Shaw (2002) • Overall, the document is not well structured and wording is often unclear, making assessment difficult • In regard to Q3. it should be noted that methods available are not capable of detecting small effects, which is due to high natural variability of rainfall. • The authors state Queenstown and Strathgordon are good westerly control areas. They do not mention that some findings may actually indicate higher rainfall due to cloud seeding in Queenstown (though certainly no proof for that is brought forward in this article either). • Private communication with Pook revealed missing values were in-filled by extrapolation from neighbouring sites. This suggests control areas contaminated from target area at various times

Name of document	**Ryan, B.F. & King W.D. (1997)**, A *Critical Review of the Australian Experience in Cloud Seeding*, In: Bulletin of the American Meteorological Society, Vol. 78, No.2, February 1997, p. 239-254.
Year of document	1997
Location	Australia
Overview of the document	Review of 47 years of cloud seeding experiments in Australia. Effectiveness of cloud seeding and/or establishing scientifically well funded proof for effectiveness is limited to certain meteorological conditions; stratiform clouds undergoing orographic uplift seem most favourable for cloud seeding. The Tasmanian experiments provide strong and convincing evidence cloud seeding is effective there when cloud-top temperatures are between -10°C and -12°C, stratiform clouds undergoing orographic uplifting and in a (maritime) south-westerly airstream, in autumn and winter.
Method	Review of experiments (aim of experiment, meteorological characteristics, design of analysis, results of analysis, critique, procedures)
Findings	• The review focuses on previous experiments in Australia to assess the static cloud seeding hypothesis, nearly all experiments in Australia are of that kind; • Cloud seeding programs can consist of two types (or combination) of research: statistical and/or physical programs. Statistical programs aim to measure increased precipitation in target area using a randomised seeding program, and physical programs aim to determine and understand the precipitation process; • Three main statistical programs have been the Climax-experiments in the US, the Israeli experiments and the experiments in Australia. Rangno and Hobbs (1993) argue the Climax and Israeli experiments that were claimed to be successful, fail to establish the efficacy of cloud seeding. • Physical cloud seeding programs in US (Colorado Orographic Cloud seeding Experiment – COSE) show there is evidence orographic clouds can cause significantly more precipitation as a result of cloud seeding. Cotton and Pielke (1992) further conclude it is not possible (yet) to produce statistically significant effects from all supercooled cumuli and orographic clouds. • Physical studies can provide plausibility to any statistical inference of cloud seeding effectiveness. • Between 1947 and 1994 a number of experiments were conducted in Australia. The early experiments can be described as 'black boxes'. Over time these evolved to 'gray boxes' where seeding was based on direct physical observations. The later experiment designs included both a statistical evaluation and a physical understanding of the process CSIRO single cloud experiments (1947-56) • Radar observations showed seeding of dry ice on cumulus clouds resulted into precipitation rapidly and that the rain would not have occurred otherwise. Chance for success was highest between -7°C and -15°C. • Silver iodide (AgI) experiments showed it is an effective agent for clouds with top level temperatures of below -5°C. Precipitation occurred 20-25 minutes with cumulus clouds and somewhat later with stratiform clouds. Significantly more rain fell from seeded clouds ($p<0.02$). • These results led to CSIRO embarking on a program of area experiments. CSIRO area experiments (1955-63) in Snowy Mountains, New England, Warragamba, SA • The aim to assess whether rain could be increased with AgI seeding in a specified area; • A randomisation scheme determined what area was target and control. Only the experiment in the Snowy Mountains produced statistically significant evidence of increased rainfall of 19% with a significance of 95% ($p<0.05$). Two experiments even produced negative results (at a low significance level). The results were overall unconvincing.

- In addition all experiments showed decreasing results with time. This was puzzling. Some authors brought forward the persistence effect of AgI. Bigg and Turton (1986, 1988) state to have found evidence for this. If true, it invalidates analysis based on target – control and seeded-unseeded days. There is no evidence of a physical mechanism transporting bacteria into the clouds and therefore the hypothesis is speculative.
- New experiments were designed by CSIRO to take deterioration of effects over time into account, as well as the variability of results with seeding conditions and with rainfall gradients.

Seeding by state governments (1965-1971)

- These experiments were mainly of an operational nature. CSIRO advised but did not participate
- Experiments were conducted in Vic, NSW, Qld, SA and WA
- In all cases where analysis was done the results were either inconclusive or controversial. In addition, ongoing debate on an experiment in Vic and the interpretation of its results. This debate did not increase the credibility of cloud seeding in the scientific community.

Experiments in Tasmania,

Exp I 1964-71

- The design included 3 designated control areas to be unseeded on occasions that target area was seeded. Time pairs of 12 days, seeded/unseeded. The schedule was carried out in alternate years only to prevent effects from persistence (if any)
- The results show 30% rain increases in autumn at a significance level of 97% ($p<0.03$). For other seasons the results were inconclusive. HEC decided to further explore cloud seeding as a means for water resources management. Hydro power has a high benefit/cost ratio compared to oil-powered generators that are used alternatively if water supplies are low.

Exp. II 1979-83

- Concept of suitable day was introduced and was defined for both stratiform and cumulus clouds. Seeded/unseeded days as 2:1. Distance for seeding from target area was 1 hr upwind for stratiform and 30-min for cumulus clouds. Moreover, suitability criteria were enhanced significantly by physical observation.
- Sample size over 5 year period was 66 days.
- Rainfall increased for stratiform clouds in south-westerly air streams by 37%
- The experiment represents a shift from black box to gray box approach where physical criteria were used to define a seeding window. Evidence for downwind effects was not produced, but may be due to limited sensitiveness of statistical analysis.

Tas III 1992-94, drought relief

- Seeding agent was dry ice.
- Area: east coast and midlands (1992-1994).
- Randomised trial of three year duration. Statistical evaluation using conventional regression analysis with dummy variable and also double ratio analysis. No bootstrap analysis to determine confidence limits of DR.

CSIRO Emerald experiment (1972-75)

- Large cumulus clouds of which seeding was expected to be valuable for irrigation and mining. Dry Ice and AgI were used as seeding agents. Establishing statistical evidence was complicated by extreme spatial and temporal variability of natural rainfall in the area.
- Conclusion was that opportunities existed but it would need many years to be able to produce a statistical reliable answer. The exp was abandoned because of a lack of resources

CSIRO experiment in western Victoria (1979-80)

- Experiment in major wheat growing area and involved a new degree of sophistication in experimenting in Australia. It followed guidelines developed by WMO, being: **1) clouds suitable for seeding have to occur reasonably frequently, 2) rain patterns need to be such that there is a reasonable chance of establishing evidence of seeding effects within 5 yrs, and 3) the experiment costs are well below the economic benefits**.
- Suitable day definitions were based on Tasmania experiment experience
- Experiment included extensive physical measurement
- Number of suitable days was expected to be reasonable; however after two years of experimenting it was concluded that suitability conditions were grossly overestimated (less suitable days, cloud-top temperatures of -25°C and lower. Based on this it appeared the costs were higher than benefits and the experiment was abandoned
- All subsequent cloud seeding experiments have been randomised and incorporated a physical program, a statistical analysis and an economic evaluation.

Western Australian northern wheat belt cloud study 1980-82

- The study showed there were many clouds with a reasonable potential for seeding. Simulations

	showed that a 30% rainfall increase was needed for (being able to) detecting the effects in a 5-yr experiment. To detect a 10% increase in rainfall one would need a 20 year experiment • Although the economic analysis showed costs of the experiment would be well below the expected benefits (extra yield per hectare) there was insufficient commitment for resources on a 20-yr timescale. Melbourne Water Corporation / CSIRO experiment 1988-92 • The experiment included seeding of stratiform clouds with and without embedded cumulus. Especially orographic uplift and cloud tops higher than -10°C proved favourable. However, no significant evidence was established. Tests between target and control showed a significant increase. Melbourne Water concluded there was insufficient evidence to proceed. Critical assessment of past cloud seeding activities in Australia • Many experiments produced negative or doubtful evidence on the effectiveness of cloud seeding • The current view of w ater managers in Australia is that CS is a marginal water-management tool • CS operations need to be based on objective water management and scientific goals that have real cost-benefit justification • The only mainland study with statistically significant inc rease in rainfall is the Snowy Mountains experiment (1955-59) • Extreme care needs to be taken in statistical design and conduct of these experiments • The basic statistical rules required to design and evaluate a cloud-seeding experiment were developed in light of the Tasmanian experiments and have since been applied in all subsequent cloud-seeding experiments in Australia. • Hydro Tasmania is convinced of the economic success of the experiments. But it is still seen as a marginal benefit. • Seeding is more effective on days when the clouds have high liquid water contents (0.2 to 0.5 gm^{-3}) • Criticism on design of cloud seeding experiments stems from Dr. E. Bigg on the basis of his persistence effect hypothesis and states previous experiments have been contaminated by this effect and are therefore underestimating the effect of cloud seeding. Bigg's hypothesis is currently based on little evidence and would need more microbiological observation and analysis; the hypothesis remains speculative until more evidence is provided. Circumstances where rain enhancement experiments are not favourable in Australia • Systems usually unsuitable for seeding: frontal systems, airstreams from land/plains and closed lows and deep cloud systems • Inland plains of are not particularly suitable for seeding. However, the potential economic cost savings (from moving cattle and crops) outweigh the costs of cloud seeding by a factor 2 (King 1982). • The long timeframe (often > 5 years up to 20 years) needed to produce statistically significant evidence is often long and requires commitment of substantial resources. This often proofs problematic. Long timeframe is needed due to high variability of rainfall over time. • Spatial variability of rainfall in summer rainfall areas of northern Australia requires expensive and large network of gauges Circumstances where rain-enhancement experiments might be beneficial • Orographic regions where the flow over the mountains substantially enhances rainfall • Autumn and winter are effective seasons for cloud seeding in Tasmania • Most suitable clouds are stratiform clouds in a maritime south-westerly airstream have proven to result in 37% additional rainfall • On average 18 suitable days occurred during Exp II and created 197 mm of extra rain • Cost/benefit ratio estimated by Hydro Tasmania is 1:13 or enhancement of runoff into Tasmanian storages by 10-20% New developments in cloud seeding techniques • New instrumentations (fairly expensive and hence not yet applied in Australia at time of this article) and the numerical modelling techniques. • New modelling techniques are able to simulate the generation of rain from cloud systems. Could, among others, be useful in devising aiming strategies. General • Australian physical programs were modestly resourced compared to some US physical experiments • From the statistical viewpoint, the most successful experiments have been in Tasmania. These experiments are important as benchmark experiments to other studies. • Currently, there is no evidence that the Tasmanian experiments are subject to the same errors Rangno and Hobbs (1995) suggest occur in the analysis of the Israeli experiments. • Factors that contribute to experiments failing are: inadequate scientific knowledge, flawed planning process, scientific issues ignored by funding agencies, c hanges in project management, poor

	performance by scientists. • **Currently there is insufficient knowledge to either reject totally or accept completely the persistence arguments proposed by E. Bigg.** Conclusions Over 47 years cloud seeding experiments and microphysical investigations of the clouds have shown that cloud seeding is effective for limited meteorological conditions in stratiform clouds undergoing orographic uplift. In Tasmania there is strong statistical evidence for rainfall enhancement for clouds with cloud-top temperatures of between -10°C and -12°C in a south-westerly airstream. For water management purposes increases of 5-10% in the rainfall makes cloud seeding economically viable.
Limitations	•

Name of document	**Searle, I.L. & Nebel, C. (1998)**, *Cloud Seeding. The Tasmanian Experience*. By: Ian L. Searle, Christina Nebel of Hydro Tasmania. WR 1998/042, 5th edition, September 1998
Year of document	1998
Location	Tasmania
Overview of the document	Overview of the Tasmanian experience with cloud seeding including Stage I (1964-71), Stage II (1979-83), Drought Relief (1988-91) and Dry Ice Exp Stage III (1992-94).
Method	Literature review
Findings	Stage I (1964-71) • Improved design of experiment compared to previous mainland experiments • Despite the design (I year seeding, one year no seeding) to prevent (long term) persistence effects, during season the effects of cloud seeding seemed to deteriorate suggesting persistence effects were contaminating the analysis • In spite of this the analysis showed a 19% increase (TC double ratio of 1.19) at a significance level of 3% (97% probability the results are not coincidence) • A regression analysis returned a +30% rainfall in Autumn and +12% rainfall in Winter • Cost-benefit ratio for HEC 1:13 • Bigg (1985) and Searle (1991) contribute diminishing effects to dispersion of AgI/persistence during season. Stage II (1979-83) • The experiment involved a range of improvements in respect to aircraft, equipment, instrumentation and experimental design (E.G. the introduction of 'suitable day' entity) • Shaw (1984) concluded the cloud seeding resulted in +116mm in Target West (sum seeded days) and +66mm in Target East. • Searle (1994) showed +164 mm in total target area or 3.7 mm on average per seeded day at significance level of 3% (regression analysis). Double ratio was 1.36, indicating a 36% increase. Total of 44 seeded days. Drought relief operations (1988-91) • Operational mode of CS over an enlarged area • 26 seeded days; no unseeded randomisation was applied. Seeding was done when circumstances suitable • Based on historical rainfall analysis using the Percent Normal Rainfall Analysis it was concluded rainfall increased by 30% in target area compared to adjacent areas • Figure 11 (p.21) suggests +25-30% rainfall in Queenstown, Rosebery and Tullah and +20-25% in remainder of WCC Dry Ice Exp Stage III (1992-94) • Significant but smaller rainfall effects were measured than with AgI as agent • There were only detectable, significant effects within 3 hours, suggesting there were no delay effects and/or there is too much natural variability within the 24 hr timeframe to establish significant results • Cost benefit ratio to HEC at 1:6 • Effectiveness of dry ice is lower than AgI because AgI has longer lasting durability and is slower acting. Moreover, AgI has no risk of overseeing unlike dry ice where overseeing can actually reduce rainfall

<table>
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If existent, persistence underestimates the total seeding effect
Research by Bigg indicates rainfall increases were detectable on days following seeding operations as well
Also the effect was proportional to the amount of seeding done in previous weeks: the cumulative seeding index
Bigg pooled results from 5 of the Australian experiments (1955-64) and noted large increases east (downwind) of the seeded area (fig 14, p.24)
As the seeding seasons progressed, the ratio of target area rainfall to control area rainfall increased significantly, reducing the ability of the experiment to detect seeding effects
To test Bigg's theory, Hydro Tasmania analysed all seeded months (instead of days) in a percent normal analysis (reference to report missing!)
Results suggest +20% rainfall in some WCC areas among which Queenstown, Tullah and Rosebery (5% error margin). (Fig. 17, p.25)

Current status of CS in other states

Victoria 1992; no significant effects were established in target, but there were in the buffer area. Bigg claims significant persistence effects
NSW 1994-95; successful drought relief program
Other; little CS activity since 1970
Reasons include short term vision, inability to predict clouds, adverse publicity by CSIRO 1983 (which was subsequently recalled in 1984)

Scientific consensus (internationally)

WMO states that in relation to orographic clouds (as in Tasmania) "statistical analyses suggest seasonal increases (usually over the winter/spring period) in the order of 10 to 15% in certain project areas."
The Weather Modification Association of USA (WMA) states the effectiveness of CS depends on a wide range of criteria (weather of area, design experiment, etcetera)

Technical and operational requirements

Suitable clouds in Tasmania include stratiform and cumuliform types and mixtures of both
Information on cloud suitability, responsibilities and data logging is covered in other Hydro Tasmania documents

Environmental impacts AgI (dry ice and hydroscopic salt are not relevant in regard to this study)

AgI: 0.5 kg/hr is seeded, 20-50% will fall on earth in rainfall, 25 to 50 kg is dispersed per annum (reaching ground) which is less than 2.0gr/km2. AgI binds strongly to clay particles in the ground. It is not soluble in water. The max permissible level of silver in water is 1000 times greater than that found in rainwater from seeded clouds
There is no real threat to humans, plats, or animals from AgI as seeding agent in the study area and off-site effects are extremely unlikely.

Impact of additional rain

Generally, the community within a target area will be largely unaware that seeding is enhancing rainfall. (No evidence, no sources or references provided!) This is so because the amount of extra rainfall is expected to be between +5% and +30% which is well inside the range of natural variability
CS may reduce the risk of soil erosion that may otherwise occur after a period of drought or normal rainfall.
Seeding may need to be suspended by a referee in times of excessive rainfall or high river levels. Hydro Tasmania defined 'suspension criteria' to avoid adverse impacts on target area or on other up- or downwind areas
In downwind areas there may be concerns for increased or reduced rainfall (both issues seem to occur). In areas with relatively uniform topography (or does author mean flat?) rainfall increases can occur to 250 km <u>downwind</u> of target area. In Tasmania the argument of uniform topography is not valid and downwind effects do not seem to extend that far. (this weakens the strength of the argument mentioned in some media articles)
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<tr><td>Limitations</td><td>
The substantiation of various statements is fairly limited, especially in regard to the magnitude of potential persistence impacts & CS effects outside target areas.
Figures on p. 21 and 25 are based on single ratio analysis alone; no reliable conclusions are to be drawn from that.
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Name of document	**Shaw, D. (2002)**, *Comments by Dr. Doug Shaw* on "An Evaluation of Cloud Seeding Operations carried out in Tasmania by Hydro Tasmania", CSIRO Mathematical and Information Services. Ref: WM 2002/004.
Year of document	2002
Location	Tasmania
Overview of the document	Comments on the evaluation by Pook and Budd aim specifically on the issues of sample sizes (availability of data and representation of population), historical analysis of rainfall with percent normal analysis and the authors' conclusions and recommendations.
Method	n/a
Findings	Sample size • Pook and Budd repeatedly use the argument of limited sample size to question the *significance* of results. This is a false argument. Statistical significance is the probability that a result could have occurred by coincidence / without the effect being tested. An effect is tested 'significance' if probability of coincidence is very small (p<0.05 or even <0.01). The calculation of probabilities takes sample sizes into account (red. Which means an effect needs to be fairly strong to be observed or proven in a small sample. Extra target effects for instance are expected to be non-existent or small, but small sample sizes do not allow this to be detected). • The power of a statistical test is the probability that an effect exists but it is failed to find it. • There is a trade-off between significance and power. Increased significance means reduced power, and vice-versa. • Cloud seeding experiments so far were designed to establish high level of significance. Since sample sizes are small, the power to detect effects is reduced, • Small sample sizes have a smaller chance of being *representative* for the population of units about which to draw conclusions. Randomisation should minimise this risk. It is appropriate examine the representativeness of the sample size and verify the balance achiev ed by randomisation. • The samples of the experiments may exhibit limited representativeness and balance Historical analysis of rainfall data • Pook and Budd used the 'percent normal analysis' as an alternative method to detect the effects of seeding by comparing 'seeded' periods with historical periods. (method is often applied in operational phases when no randomised unseeded periods are defined) • Percent normal analysis is seen as a contentious approach for evaluating the effects of cloud seeding • Pook and Budd have applied a 'relatively unsophisticated' form of the method • The authors cast doubt on the positive results for seeded months in target area showing similar results occurring at Queenstown. They fail to address whether results were more positive in target than in Queenstown. (possible events are the seeded months are wetter months anyway, or, Queenstown may be affected by extra-area effects if cloud seeding) • Pook and Budd fail to review analyses that claim to show extra-area effects Authors' conclusions and recommendations: • The re-assessment is basically similar to analyses in reports of Exp I and II • The authors mention the small sample size to question the effectiveness of cloud seeding, but in the end conclude there is strong evidence for effectiveness • The authors mention the possible existence of persistence effects. They follow Ryan and King (1997) who say persistence is no longer than 24 hrs. Other authors (Bigg, Turton Bowen and Long) do not agree on this. • Shaw underwrites the importance of applying randomised unseeded days in future operational phases of cloud seeding to further sophisticate future research.
Limitations	•

Name of document	**Shaw, D., King, W.D. and Turton, E. (1984)**, *Analysis of Hydro-Electric Cloud Seeding in Tasmania 1979-83,* Report to HEC, CP 394, December 1984.
Year of document	1984

Location	Tasmania
Overview of the document	Original report on the effects of cloud seeding Experiment II 1979-83. Results have been presented in other articles as well – hence this review is brief.
Method	Double ratio and regression analysis. Both analyses have different characteristics and emphasize different aspects of the data. DR is most effective when there is a multiplicative effect of seeding. RA allows more flexible parameterization of effects.
Findings	• No evidence for effects associated with target east were found • West produces significant effects compared to immediate upwind control area (both DR and RA) • Narrowing the analysis down to days with westerly winds (between 231° and 300°), then both DR and RA deliver significant effects of seeding in target west, significance of 1% and 2% respectively (i.e.: 99% and 98%) with direct upwind control area; • TE results are significant for DR with upwind control, and only marginally for RA; • Overall, strong evidence for effectiveness in target west on westerly wind days; • For TW increase in rainfall is 2.44 mm per day and on westerly wind days 3.15 mm per day. For TE there is an unsure increase of 2.46 mm per day.
Limitations	•

Name of document	**Smith, E.J, Veitch, L.G., Shaw, D.E. and Miller, A.J. (1979)**, *A Cloud-Seeding Experiment in Tasmania*, In: Journal of Applied Meteorology, Vol. 18, p. 804-815, June 1979.
Year of document	1979
Location	Tasmania
Overview of the document	Results from Tasmania's first cloud-seeding experiment 1964-1970. The experiment uses a target area and three control areas. Seeding was on a random basis using silver-iodide smoke. Evidence is presented that seeding increased rainfall in the eastern half of the target area during autumn. Results have been presented in other articles as well – hence this review is brief.
Method	Double ratio and regression analysis. H0 = seeding has no effect on rainfall in the target area. Randomisation scheme with pairs of 10-18 days of seeding/no-seeding. A year of seeding was followed by a year of not seeding to prevent any possible persistent effects of seeding. The northwest control area was added after two years; gauges in western parts of the target were not well correlated with the other two control areas.
Findings	• The mean annual rainfall (19??-??) in the target varies from 750 mm in target east and 2300 mm in the target west. Stratiform clouds tend to dominate autumn and winter and cumulus clouds summer; • Upwind seeding 30 minutes for cumulus clouds and 45 minutes for stratiform clouds; • If the target area was upwind from any control area, clouds were not seeded. This may have diluted the results but at least cannot have introduced any contamination. • The seeding time per year progressively increased, reflecting the increasing skills of the flying crews; • Double ratio provides an estimate of the factor by which mean rainfall has been increased by seeding, if applied over a sufficient length of time; • Effects proved to be significant for target east and west in autumn, target west in winter and target east in summer. • The authors suggest seeding is especially effective in case of prefrontal stratiform clouds. • Magnitude of effects is combination of multiplicative and additive effect; and was not expressed in one single value per season and area. But % in autumn were +30% target east and +9% in west (plus an additive increase)
Limitations	•

Name of document	**Watson, B. (1976),** *A review of Cloud Seeding in Australia and its Potential Impact on Water Resources Management*, In: ?, p. 181-192, 1976, Watson of Hydro-Electric

	Commission, Hobart, Tasmania.
Year of document	1976
Location	Tasmania
Overview of the document	The conclusion is that cloud seeding would be a very economic proposition Results of the Tasmanian experiments have been presented in other articles as well – hence this review is brief and focuses on the potential contribution of cloud seeding in terms of water resources management.
Method	Economic evaluation
Findings	• The increases in runoff into water storages have been assumed to equal additional rainfall because cloud seeding generally takes place in wet seasons when the soils are generally saturated anyhow; • Based on simulations, estimates were made of additional yield attributed to cloud seeding, and compared to the costs of cloud seeding. The value of the energy is partly due to increases in capacity and partly due to savings of thermal fuels; • The conclusion is that cloud seeding would be a very economic proposition • The need for experimental data (i.e. not seed when conditions are suitable) means some trading of yield for quality data. • The approach of the economic valuation is rather unrefined / rough.
Limitations	• Rough assumptions and hence rough economic evaluation