TERM OF REFERENCE 1: PREPAREDNESS AND PLANS – FLOOD LEVEES

The effectiveness of the strategies, preparedness and plans relating to managing flood risk in Tasmania that were in place prior to the June 2016 floods occurring; including ***existing and potential levee systems****.*

---

1 FLOOD LEVEES

(a) The purpose of flood levees is to protect assets and infrastructure that have been built on the flood plain and would be at risk during a flood event.

(b) There are flood levees in both Launceston and Longford and these were effective during the June floods.

(c) The Launceston Flood Authority is responsible for flood protection in Launceston.

(d) Hydro Tasmania's involvement in flood levees in Launceston relates to the relationship between flows from Trevallyn Dam, the practice of silt raking to remove sediment from the Upper Tamar estuary and the role sediment plays in the effectiveness of the flood levees.

(e) The ongoing collaboration between Hydro Tasmania and the Launceston Flood Authority to assess this issue is elaborated on below.

(f) In addition to a need for flood levees in areas developed on flood plains, the identification and mapping of areas that are known to, or may be regularly flooded, is the preferred approach to provide a long term and more cost effective mitigation of potential flood impacts and to inform future planning. This systematic assessment is supported by the 2016 Tasmanian State Natural Disaster Risk Assessment (UTAS 2016).

(g) The management of areas that are subject to flood risk is best implemented via the *Land Use Planning and Approvals Act 1993* through Planning Schemes by providing a framework for the management and restriction of the use and development of land.

2 LAUNCESTON FLOOD LEVEES

(a) The effective area that water can travel safely through is a product of the river width and depth of the water. Increasing the water depth by containing the flow between levees enables more water to flow through the same width. In order to maintain the depth of the river channel below the levee crest the Launceston Flood Authority has previously undertaken a dredging program to remove sediment, and more recently a silt raking program which is considered more cost effective. Removing the sediment maintains the depth available for the water to flow through.

(b) A collaboration has been established between Hydro Tasmania and the Launceston Flood Authority since 2015 to progress studies on the interaction between flows released from Trevallyn Dam, silt raking and sediment levels in the Upper Tamar estuary that may influence the effectiveness of the flood levees.

(c) In August 2015 Hydro Tasmania staged a managed release of 25 cumecs of water for three days over the Trevallyn dam as a trial to assess the effectiveness of a controlled release of water from Trevallyn Dam, in conjunction with silt raking operations and strong tide events, to assist the removal of sediment from the Upper Tamar estuary. Approximately 19,000 cubic metres of sediment was removed from the Yacht Basin and Kings Wharf areas of the Upper Tamar Estuary during the trial. It took approximately 3 months for the silt to return to pre-trial levels.

(d) Prior to the June 2016 flood event silt levels in the upper Tamar Estuary area were at their highest level since 2010 and post flood at the lowest levels measured since bathymetric surveys commenced in 2008. Publicly available information indicates that during the June 2016 flood over 800,000 cubic metres of sediment was removed from the Upper Tamar estuary between Kings Bridge and the University of Tasmania including approximately 380,000 cubic metres from the Yacht Basin area.[1]

(e) Hydro Tasmania and the LFA have continued collaboration on the issue of flows, silt raking and the role of sediment in the effectiveness of the Launceston Flood levees. The results of the 2015 silt raking trial and the

---

[1] As reported in an article published in the Examiner on 26 November titled “Floods scour sediment from estuary” by Doug Dingwall.

performance of the levees and sediment movement during the 2016 floods provide valuable inputs to this collaboration. Additional studies and scenario based analyses are currently being conducted by the LFA and the results of these studies will assist to develop actions as required to ensure the ongoing effectiveness of the Launceston flood levees.

3 FLOOD MAPPING

(a) While flood levees can provide short term relief to the potential impact of flooding, the identification of areas that are known to, or may, be regularly flooded, is the preferred approach to provide a long term and more cost effective mitigation of potential flood impacts and to inform future planning. This systematic assessment of flood hazards risks in riverine systems is supported as a proposed treatment in the 2016 Tasmanian State Natural Disaster Risk Assessment. Flood mapping needs to be completed for this approach to be implemented. At a minimum a program that identifies areas that may be flooded with a 2%, 1% and 0.5% recurrence interval[2] should be identified, and include consideration of climate change and in particular climate variability.

(b) The management of areas that are subject to flood risk is best implemented via the *Land Use Planning and Approvals Act 1993* through Planning Schemes by providing a framework for the management and restriction of the use development. While the flood prone areas have been identified in a number of planning schemes across the State, the extent of this mapping has been limited and ad hoc in nature, without a standardised approach or methodology[3].

(c) Under the current proposed reforms, which would result in the development of a Statewide Planning Scheme, flood hazards are to be managed through the Riverine Inundation Hazard Code. The purpose of this code is to manage use and developments in areas at risk from periodic or permanent riverine inundation so that:

   (i) people, property and infrastructure are not exposed to an unacceptable level of risk;

---

[2] That is, 1 in 50 year, 1 in 100 year and 1 in 200 year floods, which are the frequencies commonly used for land use planning purposes.

[3] 2016 Tasmanian State Natural Disaster Risk Assessment, UTAS, 2016, p.81.

(ii) future costs associated with options for adaptation, protection, retreat or abandonment of property and infrastructure are minimised;

(iii) the risk from riverine inundation hazard to other properties or public infrastructure is avoided or reduced; and

(iv) development is precluded on land that will unreasonably affect flood flow or be affected by permanent or periodic flooding from a riverine watercourse.

(d) However, the Explanatory Document for a draft of the Statewide Planning Scheme (March 2016), requires that local Planning Authorities take responsibility for flood mapping using their own riverine inundation data or data from other sources in determining the extent of the riverine inundation hazards without any consideration of a standard annual exceedance probability or consequence framework. Hydro Tasmania supports the development and implementation of a standardised approach to the mapping of flood prone areas across the state.

TERM OF REFERENCE 3: STATE-WIDE WATER STORAGE MANAGEMENT

The causes of the floods which were active in Tasmania over the period 4-7 June 2016 including cloud-seeding, ***State-wide water storage management*** *and debris management.*

1 CONTEXT

1.1 Cause of the Floods

(a) It is clear that the flooding that affected northern Tasmania (including the Mersey, Forth, Ouse and South Esk rivers) during the relevant period was directly caused by "*a persistent and very moist north-easterly airstream*" which resulted in "*daily* [rainfall] *totals* [that were] *unprecedented for any month across several locations in the northern half of Tasmania*", in some cases in excess of 200mm.[1]

(b) This paper addresses Hydro Tasmania's water storage management prior to and during the floods.

1.2 Overview

(a) In 2014, Tasmania celebrated 100 years of hydro industrialisation and the role it played in the development of Tasmania. Hydro Tasmania believes that understanding the design and purpose of the hydropower infrastructure that was developed to bring electricity and investment to the state is an important starting point to provide context for our submission. The Tasmanian hydropower system design and operation is highly complex and is generally not well understood in the community. We understand that key stakeholder groups are seeking to better understand the role that hydropower operations may have in controlling or contributing to flood events in Tasmania.

(b) The hydropower infrastructure in Tasmania was designed and installed for the primary purpose of generating hydro-electricity. Flood mitigation was not a primary objective in the design of Hydro Tasmania's dams when the schemes were developed, and any flood mitigation benefit is a by-product of their hydro-generation operation. Some dams in other parts of the world have been intentionally designed for multi-purpose use with the multiple objectives, such

---

[1] Bureau of Meteorology's Special Climate Statement 57, issued on 17 June 2016.

as hydropower generation, water supply and flood mitigation and control (such as Wivenhoe dam in Queensland). As a result of its design, the Tasmania hydropower infrastructure has limited capacity for flood mitigation or control. This point is important for context and is elaborated on during this submission.

1.3 Hydro Tasmania's role and governance

(a) Hydro Tasmania is a "statutory authority" within the meaning of the *Government Business Enterprises Act 1995* (Tas). Its primary governing legislation is the *Hydro-Electric Corporation Act 1995* (Tas)[2].

(b) Hydro Tasmania's principal purpose is to "*efficiently generate, trade and sell electricity in the National Electricity Market*"[3].

(c) Its principal objectives are to perform its functions and exercise its powers to:

  (i) be a successful business by operating in accordance with sound commercial practice and as efficiently as possible; and

  (ii) achieve a sustainable commercial rate of return that maximises value for the State of Tasmania in accordance with Hydro Tasmania's Ministerial Charter and having regard to the economic and social objectives of the state[4].

(d) Hydro Tasmania has been conferred the access rights to significant water resources for the purposes of hydro generation in Tasmania[5]. This is subject to stringent legislative regulation[6].

(e) Hydro Tasmania's Ministerial Charter also contains several "Strategic Expectations" on Hydro Tasmania, including to:

  (i) "prudently manage its water resources consistent with the long run energy capability of its system" and

---

[2] See section 5 for a list of Hydro Tasmania's functions and powers, which are subject to the limitations set out in sections 7 and 8.

[3] Section 2.1 of Hydro Tasmania Ministerial Charter (November 2012), issued under the Government Business Enterprises Act 1995 (Tas)

[4] Section 2.2 of Hydro Tasmania Ministerial Charter (November 2012)

[5] An annual average of 15,364 gigalitres of water flows through its power stations.

[6] Hydro Tasmania holds a Special Licence under Part 6, Division 6 of the Water Management Act 1999 (Tas) (WMA) and thus, is a "water entity" within the meaning of that Act. There have a been a large number of "hydro-electric districts" created for the purposes of the WMA. On 9 June 2000 Hydro Tasmania and the Minister entered into the Special Water Licence Agreement pursuant to clause 7(2) of Schedule 4 of the WMA, which has been amended a number of times, the most recent being dated 11 September 2012.

(ii) "act in a socially responsible manner and take all reasonable steps to reduce the risk of adverse effects on the environment that may result from Hydro Tasmania's activities".[7]

(f) Hydro Tasmania takes its obligations with respect to managing the water resources under its care extremely seriously and has in place a robust governance framework to ensure compliance. Its commitment to public safety has primacy and is ingrained in its processes and systems.

1.4 Overview of Hydro Tasmania's Water Assets

Catchments and Storages

(a) The "hydro-electric districts" that Hydro Tasmania administers under the *Water Management Act 1999* (Tas) (**WMA**) includes 45 of Tasmania's major lakes and at least 1200 km of natural creeks and rivers.

(b) These areas are broken down into six major river catchments:

(i) South Esk – Great Lake catchment;

(ii) Mersey-Forth catchment;

(iii) Derwent catchment;

(iv) Gordon catchment;

(v) Anthony Pieman catchment; and

(vi) King catchment.[8]

(c) Hydro Tasmania categorises its primary water storages into three broad sizes (Major, Medium or Minor) based on the typical time required to fill or empty the storage under normal inflow/weather conditions (known as the "the life cycle of the storage"). The following table lists the storages against their appropriate category.

---

[7] Section 2.3 of Hydro Tasmania Ministerial Charter (November 2012)

[8] A map of the major storage catchments and power stations in Tasmania is included at Annexure A.

MAJOR (Long Period Cycling)	**MEDIUM** (Annual Cycling)	**MINOR** (Run of River)
South Esk–Great Lake Great Lake **Gordon** Lake Pedder Lake Gordon	**Mersey-Forth** Lake Rowallan Lake Mackenzie Lake Gairdner **Derwent** Lake Echo Bronte Lagoon + Bradys lake + Lake Binney + Tungatinah Lagoon **Anthony Pieman** Lake Plimsoll Lake Murchison + Mackintosh **King** Lake Burbury	**South Esk-Great Lake** Lake Trevallyn **Mersey-Forth** Lake Parangana Lake Barrington Lake Paloona **Derwent** Lake Laipootah Wayatinah Lagoon Lake Repulse Cluny Lagoon Lake Meadowbank **Anthony Pieman** Lake Rosebery Lake Pieman

(d) Other storages (such as Lake Augusta which is the size of a medium storage) are not ordinarily included in this list because of either their small capacity or the nature of their water conveyancing, for example if they are not closely linked with a power station.

Water Management Operations Procedures

(a) The operation of the Hydro water storages is governed by a set of Storage Operating Rules (SOR) discussed below. The storages are monitored and controlled 24/7 from the Hobart office for the purposes of dam safety and water management. Each week Hydro Tasmania plans which power stations it will run and when for the week ahead, using complex algorithms and planning software that takes into account factors such as expected rainfall, expected price outcomes, delivery risks and outages, expected usage, capacity of various dams and spill likelihood, and the value of water in different locations, and a range of other factors.

(b) Hydro Tasmania monitors and changes priorities and determines which storages to operate in real time, operating within Storage Operating Rules for each storage, the National Electricity Rules and other governance frameworks, and resolving and responding to issues, and making changes as additional information is made available.

1.5 Explanation of Storage Position

(a) Hydro Tasmania’s core business is as an electricity generator. For this reason we express the water storage position in energy output terms, ie. as GWh equivalent. Internally we also convert inflows and changes in the storage position as yield which we measure in energy output terms (GWh). Storage 'levels' are expressed as a ‘per cent full’ in energy terms. This applies to the system as a whole, but we also refer to the level of particular lakes. The figure is relative to, but is not the same as, the actual level of water in the storage expressed as megalitres for most storage dams. Hydro Tasmania publishes water storage data on its website under ‘energy data’.

Storage Operating Rules

(a) Hydro Tasmania’s Storage Operating Rules describe how water levels and releases from the storages are to be managed. In developing the rules, Hydro Tasmania considers the attributes of the particular lake – physical, climatic, multiple-use, social, environmental and operational requirements. Adjustments to rules are made when conditions surrounding these attributes change significantly. Consultation with relevant stakeholders is undertaken where appropriate to do so.

(b) Due to the prevalence of winter rains and dry summers, Hydro Tasmania’s storage levels will vary considerably over the course of a year. Therefore, Hydro Tasmania’s preferred operating zone varies throughout the year. The preferred operating zone is a range of water levels, referred to as a band, the lower end of which leaves a reserve that can be used to generate electricity when inflows are low, both due to seasonal variations in rainfall and in the case of below average rainfall. Low storage levels result in a greater risk that Hydro Tasmania may not be able to generate electricity as and when required. Maintaining higher storage levels to protect against low inflow events requires significant investment in the form of foregone generation and revenue, which has to be funded by increased debt.

(c) Around two-thirds of Hydro Tasmania’s expected yield in a year occurs in catchments that have minimal storage capability. These storages fill over the course of a full winter/spring season (in some cases many times). Around one-third of yield occurs in catchments from the major storages of Great Lake and Lake Gordon, which rise and fall over years and present no current spill risk.

(d) In managing its storages, Hydro Tasmania must constantly balance the risks arising from:

  (i) uncertain inflows against the risk of spilling excess water without power generation and other upstream and downstream considerations including flood potential to ensure optimisation of the resource use and appropriate risk management;

  (ii) the current and potential future value of generation; and

  (iii) the risk of asset outages (including assets not owned or operated by Hydro Tasmania, such as Basslink and the National Electricity Market (**NEM**) transmission networks) against the cost of alternative generation or supply sources.

(e) Hydro Tasmania's storage optimisation is achieved by integrating water modelling outputs within its total generation portfolio of hydro and gas generation. This is in turn optimised based upon forecasts of Tasmanian electricity demand, wind generation and wholesale electricity market price with imports or exports across Basslink. This process also considers contingencies such as plant and Basslink outages.

(f) In general, as water storages fall, the energy value of stored water increases, which flows through into higher bid prices into the NEM. This in turn triggers decisions on non-hydro generation - Basslink imports and gas generation - to preserve hydro storages.

(g) Through the interaction of these factors and optimisation, Hydro Tasmania meets its Government Business Enterprise (**GBE**) obligation to maximise the value of the business for Tasmania.

1.6 Safety as a Priority

(a) Hydro Tasmania's commitment to public safety has primacy and is ingrained in its processes and systems.

(b) Public safety is the number one consideration in the management of its catchments and operation of our power stations. All Hydro Tasmania employees (including those who manage flows and water levels) must take all practicable steps, regardless of generation implications, system security and any other considerations, to protect human life.

(c) Processes for managing flows during floods are described in the Storage Operating Rules. These processes are regularly reviewed and updated.

(d) Hydro Tasmania is committed to continuous learning and improvement. In this respect, it undertook a review following the 2011 Queensland floods and has incorporated the learnings from the Queensland experience into its planning tools and operational processes.

(e) A desktop flood simulation exercise was performed in conjunction with BoM in May 2011 to test processes, protocols, decisions and notifications. This showed that the protocols were simple and robust and well executed, and identified areas for improvement which were implemented.

1.7 Background Facts to June 2016 Floods

Water Management late 2015 / early 2016

(a) The period of October 2015 through April 2016 was amongst the driest 8 month periods on record in Tasmania. When combined with the extended forced outage of Basslink that commenced on 20 December 2015 (and concluded on 13 June 2016), this resulted in hydro storage levels reaching a record low of 12.5 per cent in late April 2016.

(b) As a consequence, Hydro Tasmania's primary focus was on ensuring continuation of supply to the Tasmanian electricity system[9].

(c) Storage levels improved in May 2016, which was the wettest May on record in

---

[9] The primary response to the energy supply situation came through the Energy Supply Plan.

terms of inflows into Hydro Tasmania’s storages. During the month the storage position increased by over 10% with many of the smaller lakes either spilling for a period or approaching their full supply level (**FSL**). Notwithstanding these inflows, on 30 May, the week prior to the floods, the storages were still only at 23 per cent. As Basslink was still out of service a conservative approach was being taken to water (energy) management.

Forecast Rainfall

(a) The operations team uses forecasts from the Bureau of Meteorology (**BOM**) and other forecasting models and information to plan operations. A wide range of forecasts exist but accuracy dramatically declines for forecasts beyond 3 to 4 days. The reliability of forecast rainfall information means that it is only possible to forecast with limited accuracy three to four days ahead where and when heavy rainfall will occur.

(b) It is noted that although rainfall may be predicted, if the location varies, the actions that Hydro Tasmania may take in anticipation can vary significantly. Therefore, it is careful to ensure that it makes decisions only once information is sufficiently certain, in order to comply with its obligations and achieve its objectives.

(c) In the days leading up to the unprecedented rainfall on 5 and 6 June 2016, there was uncertainty about how much rain was going to fall and where it was likely to fall. For example:

  (i) On 2 and 3 June 2016 the forecasts were for potentially heavy rain in the North East of Tasmania (rather than the North West and central Tasmania) or that it would miss Tasmania altogether.

  (ii) By later on 3 June and into 4 June, the forecasts provided more certainty as to the location of the rainfall, but there was still uncertainty as to the expected volume.

(d) The following table sets out the flood warnings issued by BOM that were applicable for Hydro Tasmania’s catchments between 3 June 2016 and 8 June 2016. The table lists the first time each level of warning was issued for each river.

Table 1: Status of flood warnings issued in early June

BoM warning	Time/date first issued	River	Hydro catchment
Flood Watch	11.58am 3 June 2016	All northern and eastern river basins	Tasmania
Moderate	3.17pm 4 June 2016	Mersey River	Mersey-Forth
Minor	3.27pm 4 June 2016	North Esk	South Esk
Moderate	3.50pm 4 June 2016	South Esk River	South Esk
Minor	3.52pm 4 June 2016	Meander River	South Esk
Minor	4.19pm 4 June 2016	Macquarie River	South Esk
Minor	4.20pm 4 June 2016	Forth River	Mersey-Forth
Moderate (upgraded)	12.44pm 5 June 2016	North Esk	South Esk
Flood Watch (broadened)	4.15pm 5 June 2016	All Tasmanian river basins	Tasmania
Major (upgraded)	4.16pm 5 June 2016	Mersey River	Mersey-Forth
Moderate (upgraded)	5.14pm 5 June 2016	Forth River	Mersey-Forth
Major (upgraded)	9.58pm 5 June 2016	Meander River	South Esk
Minor	10.36pm 5 June 2016	Derwent (inc Ouse)	Derwent
Major (upgraded)	6.25am 6 June 2016	North Esk	South Esk
Major (upgraded)	7.21am 6 June 2016	South Esk	South Esk
Moderate (upgraded)	8.05am 6 June 2016	Macquarie River	South Esk
Major (upgraded)	8.37am 6 June 2016	Forth River	Mersey-Forth
Major (upgraded)	12.10pm 6 June 2016	Derwent (inc Ouse)	Derwent
Major (upgraded)	5.14pm 6 June 2016	Macquarie River	South Esk
Moderate (downgraded)	6.22pm 6 June 2016	Forth River	Mersey-Forth
Moderate (downgraded)	3.03am 7 June 2016	North Esk	South Esk
Moderate (downgraded)	6.46am 7 June 2016	Derwent (inc Ouse)	Derwent
Moderate (downgraded)	7.07am 7 June 2016	Mersey River	Mersey-Forth
Minor (downgraded)	7.42am 7 June 2016	Forth River	Mersey-Forth
Moderate (downgraded)	9.54am 7 June 2016	Macquarie River	South Esk
Major (upgraded)	10.39am 7 June 2016	Macquarie River	South Esk
Moderate - Derwent Minor – Ouse (downgraded)	1.07pm 7 June 2016	Derwent (inc Ouse)	Derwent
Minor (downgraded)	8.13pm 7 June 2016	Mersey River	Mersey-Forth
Minor (downgraded)	9.00pm 7 June 2016	North Esk	South Esk
Minor (downgraded)	11.29pm 7 June 2016	Derwent (inc Ouse)	Derwent

2 DESIGN AND CONSTRUCTION OF DAMS

2.1 Background information

(a) The following table lists the dams that are potentially relevant to the terms of reference, together with background information on when they were built and the enabling legislation under which they were constructed.

Dam	**Year of commissioning**	**Enabling Legislation**[10]
Mersey-Forth		
Lake Rowallan	1968	*Hydro-Electric Commission (Mersey-Forth Power Development) Act 1963* (Tas)
Lake Barrington	1969	As above
Lake Parangana	1969	As above
Lake Cethana	1971	As above
Lake Gairdner	1971	As above
Lake Paloona	1972	As above
Lake Mackenzie	1973	As above
Relevant to the Ouse		
Penstock Lagoon	1916	*Complex Ores Act 1908* (Tas)
Shannon Lagoon	1927	As above
Lake Augusta	1953	As above
Relevant to the South Esk		
Lake Trevallyn	1955	*Loan (Hydro-electric Commission) Act 1947* (Tas)
Great Lake / Poatina Power station	1966-1977	*Hydro Electric Commission (Lower Derwent Power Development and Miena Dam) Act 1966* (Tas)
Poatina Re-regulation pond	2005	*Water Management Act 1999* (Tas) (dam permit)

(b) The primary purpose of Hydro Tasmania's schemes is for hydro power

---

[10] The *Electricity Supply Industry Restructuring (Savings and Transitional Provisions) Act 1995* repealed the various construction Acts noted below which enabled the various power schemes to be built ('enabling legislation'). This did not affect the ability of Hydro Tasmania to operate and maintain the various schemes.

generation and the objective of flood control and mitigation was not included as a design objective when the schemes were developed. The design therefore limits the ability to influence flood outcomes in the operation of the system. Some of the storages also supply water for irrigation, town water supply and domestic use, aquaculture, recreational use, stock use, and environmental entitlements.

(c) Hydro Tasmania is committed to sustainable use of this shared resource, and maintaining a balance between electricity generation and those other needs.

2.2 Design of Hydro Tasmania storages

(a) In general terms, Hydro Tasmania's dams are not designed for flood mitigation (that is, they are not designed with a specific purpose in mind to prevent or reduce the severity of floods). Once they are full, any further water that flows into the storage (from any source) must flow out, either through the attached power station (where applicable) or by way of "spill".

(b) This is an important distinction from some other dams in Australia and elsewhere, such as Wivenhoe Dam in Queensland (involved in the Queensland floods in 2011), which was designed and installed with a dual purpose: water supply *and* flood mitigation, by pre-releasing water, and temporarily storing flood inflows to release gradually.

(c) Certain dams in Victoria which were involved in floods there in 2010-2011 also have flood mitigation as one of their design purposes. The relevant Victorian legislation lists a number of design and operational objectives including "flood mitigation, where possible" (ie without compromising reliability of supply and dam safety).

(d) All dams have a natural effect to attenuate floods; that is the peak outflow cannot exceed the peak inflow unless there is an operational release (eg gates or other form of outlet) to do so.

(e) Where a dam has an uncontrolled spillway (ie the discharge is purely a function of the lake water level) there is very little operational control over the flood discharge. The main contributing factor is then the lake level at the start of a flood inflow event.

(f) Hydro Tasmania does have some dams that incorporate operable spillway gates that govern the passing of operational flows and spillages through or between storages, that are considered dam safety critical plant. These often allow dynamic management of lake levels, with flexibility to store inflows up to full supply level and maximize generation from stored water. The majority of these gates represent the sole outlet for flood waters for their dams. None of these were involved in the June 2016 floods.[11]

(g) The storages upstream of the areas affected by the June 2016 floods in the Mersey, Forth, Ouse and Trevallyn rivers have fixed crest (ungated) structures, which do not have operable spillways.[12] This means that it is not possible to hold back or release flood waters by opening gates in the dam. Water will generally exit the dams into the river system downstream in three ways:

(i) Through a power station associated with the particular dam;

(ii) Via uncontrolled spilling over the dam's spillway; or

(iii) Via valves in the dam structure for the purpose of limited but controlled releases (where these exist).

3 NO DAM INFRASTRUCTURE FAILURES DURING FLOODS

3.1 Dam Safety Procedures

(a) Hydro Tasmania's Dam Safety Procedures framework is a comprehensive suite of policies, incorporating a high level policy, a long term strategic and risk management standard, and a number of operational documents setting out procedures to follow in the lead up to and during dam safety events or emergencies. This framework relates to the safety and integrity of the dams themselves, rather than downstream impacts.

(b) Hydro Tasmania's dam safety is consistent with best practice in Australia. Dam Safety Performance Review Group meetings occur six monthly, with the

---

[11] The dams with spillway gates known as 'primary protection assets' (and the schemes they are a part of) are as follows: Clarke (Upper Derwent), Crotty (King), Lake Echo (Upper Derwent), Lake St Clair (Upper Derwent), Liapootah (Lower Derwent), Meadowbank (Lower Derwent), Miena (Great Lake), and Serpentine (Gordon).

[12] Except Poatina re-regulation pond. See section 4.6 South Esk below.

most recent one having occurred on 31 May 2016. This involves an independent expert reviewing the program and providing recommendations, giving an opportunity for continual improvement. This review system has been widely regarded as an industry leading governance forum.

3.2 Actual Events

(a) The floods in June 2016 were significant and many dams exceeded their previous high levels, and the levels which are considered by Hydro Tasmania that there is a 1 in 20 year chance of exceeding.

(b) Despite these extreme events, there were no dam failures (that is, to the safety and integrity of the dams).

---

4 OPERATION OF DAMS

4.1 Operation of Hydro Tasmania’s assets prior to the June 2016 floods

(a) When Hydro Tasmania’s dams are almost full or spilling, Hydro Tasmania seeks to generate electricity from them as strongly as possible to avoid or minimise uncontrolled spill. Hydro Tasmania had already been operating storages to reduce levels in the systems that were almost full or spilling following the significant inflows in May 2016.

(b) In areas where heavy rainfall is predicted Hydro Tasmania’s practice is to draw down storages to capture as much inflow as possible by operating the associated power station prior to the rainfall occurring. . This is known as creating airspace in the dams to make room for anticipated rainfall to be collected. The desire to capture as much inflow as possible is balanced with the increased risk of having drawn too much out of the dams should the actual inflows be less than expected. The target levels for balancing this risk take account the individual schemes, rest of the hydro portfolio, availability of other supply sources (wind, gas and interconnection), time of year and confidence in forecasts.

(c) In accordance with this practice, once it became apparent that many of Hydro Tasmania’s storages could anticipate significant inflows, Hydro Tasmania actively drew down a number of storages in the relevant areas prior to the floods, by operating the associated power stations. This had the effect of creating “air space” in the dams, which reduced the total volume of water that spilled as a consequence of the rainfall and delayed the onset of the floods, as the rainfall and run-off must first fill up the dam before it spills (this is also known as an attenuation effect).

(d) Although this assisted in attenuating the flood flows, the impact that this can have is limited by the size of the dams and the amount of rainfall.

4.2 Operation of Hydro Tasmania’s assets during the floods

Overview

(a) As mentioned above, all storages considered in this review which were upstream of flooding in the Mersey, Forth, Ouse and Trevallyn, are fixed crest (ungated) structures, which do not have operable spillways. This means that it is not possible to hold back or release flood waters by opening gates in the dam. Water will generally exit the dams into the river system downstream in three ways:

  (i) Through a power station associated with the particular dam;

  (ii) Via uncontrolled spilling over the dam’s spillway; or

  (iii) Via valves in the dam structure for the purpose of limited but controlled releases.

(b) When a large volume of rainfall occurs, the dams fill up faster from rainfall than the rate at which the power stations can release the water. Consequently, the excess water flows over the dam’s spillway instead of through the power station (called “spill”).

(c) This is particularly so for minor or “run of river” storages.[13] Many of the storages that spilled during the June 2016 floods were small storages, which fill and spill quickly.

(d) The rainfall that occurred in early June 2016 significantly exceeded the

---

[13] ‘Run of river’ storages are operated by diverting river flow through the power stations before returning the water back to the river downstream. As such, unlike conventional hydro-power schemes, their dams are generally small storages.

capacity of many of these dams, causing them to spill.

(e) If a Hydro Tasmania dam is spilling, Hydro Tasmania generally continues to operate the associated power station to generate power from that storage, since at least it gets the economic benefit from the water (as opposed to the zero economic benefit from water that “spills”).

(f) The operation of a power station once a dam is spilling generally does not affect the volume of water flowing downstream, as the water simply flows through the power station rather than over the spillway. An exception is the Lemonthyme Power Station (Lake Parangana) referred to below, where the volume of water flowing down the Mersey River was reduced, as this water was diverted to the Forth River.

4.3 Operations in the Derwent river system (impacting the River Ouse)

Ouse - Overview

(a) The River Ouse is located in the Derwent Catchment. The Derwent cascade of power stations is a run-of-river system and is quite complex as the lakes have small storage capacities. Water from almost the entire Derwent catchment is utilised for hydro-electricity generating system. The freshwater portion of the Derwent catchment covers an area of approximately 7,400 km2 in south-east and central Tasmania. The area encompasses the catchments of the River Derwent and several tributary rivers including the Ouse, Nive and Dee.

(b) The River Ouse starts at an elevation of 1,210m in the central plains. It then drops over its 131km length, flowing generally in a north-south direction, through Julian Lakes (at 1,206m), Lake Augusta (at 1,152m) and the township of Ouse (at 150m) before it joins the River Derwent.

(c) In normal circumstances, some of the head waters of the River Ouse are diverted across to Great Lake (via Liawenee Canal) and the middle reaches are diverted across to Lake Echo (via Montpeelyata Canal). The maximum capacity of the canals is as follows:

(i) Liawenee Canal – 23.3m^3/sec (cumecs); and

(ii) Montpeelyata Canal – 14.16 cumecs.

(d) The creeks and rivers with the largest catchment areas which flow into the River Ouse are the Shannon River, Kenmere Creek, Blackburn Creek, James River, Boggy Marsh Rivulet, Ripple Creek and Simpsons Creek.

(e) Hydro Tasmania has the following storages which can contribute to water flow into the River Ouse:

(i) Lake Augusta;

(ii) Little Pine Lagoon;

(iii) Shannon Lagoon (from Great Lake); and

(iv) Penstock Lagoon

(f) Lake Augusta and Shannon Lagoon are located physically within the Ouse catchment, and in normal circumstances contribute water to Great Lake which discharges via Poatina Power Station into the South Esk catchment (via the Liawenee Canal). During flood events however, water can spill from Lake Augusta and Shannon Lagoon into the River Ouse and Shannon Rivers respectively in the Derwent catchment.

(g) In addition, the River Ouse travels a further 70km downstream of Montpeelyata Canal, through an additional 830km^2 of catchment before reaching the river monitoring station at Ashton Creek (approximately 15 kilometres north of Ouse township).

(h) A map and schematic of the Derwent Power Scheme is attached at Annexure C.

Ouse - Operation of Hydro Tasmania's assets prior to the floods

(a) The water level in Lake Augusta was actively drawn down in the 2 to 3 days before the heavy rainfall via:

(i) operation of Liawenee canal to transfer water away from the River Ouse and into Great Lake; and

(ii) operation of Montpeelyata canal to transfer water away from the River Ouse and into Lake Echo.

(b) The lake level in Shannon Lagoon was also actively drawn down prior to the floods.

(c) At 9am on 5 June 2016, the levels of Lake Augusta, Lake Shannon and Penstock Lagoon were:[14]

Lake	**Lake level**	**Full level**	**NMOL[15]**
Lake Augusta	1149.61	1150.62	1141.63
Shannon Lagoon	1017.57	1017.66	1016.97
Penstock Lagoon	919.78	919.86	919.30

Ouse - Operation of Hydro Tasmania's assets during the floods

(a) From a hydro-generation perspective Lake Augusta is generally considered to be part of the Great Lake catchment, as its water is transferred into Great Lake during usual operations. In extreme rainfall events, when Lake Augusta reaches capacity and spills, Hydro Tasmania uses the canals to the greatest extent possible to transfer water into Great Lake or Lake Echo, however where the amount of water exceeds the capacity of these canals, the excess water flows down the River Ouse. In early June 2016, a significant amount of rainfall fell into Lake Augusta's catchment causing the lake to reach capacity and spill in this manner.

(b) No additional water was transferred into the River Ouse via active operations during the floods once Lake Augusta was spilling. Water was not released from Great Lake into Shannon Lagoon, and water was not released from Little Pine Lagoon via Deep Creek Cut into the River Ouse. Little Pine Lagoon filled and it's water spilled into Little Pine River and flowed through to the Nive River and did not enter the River Ouse.

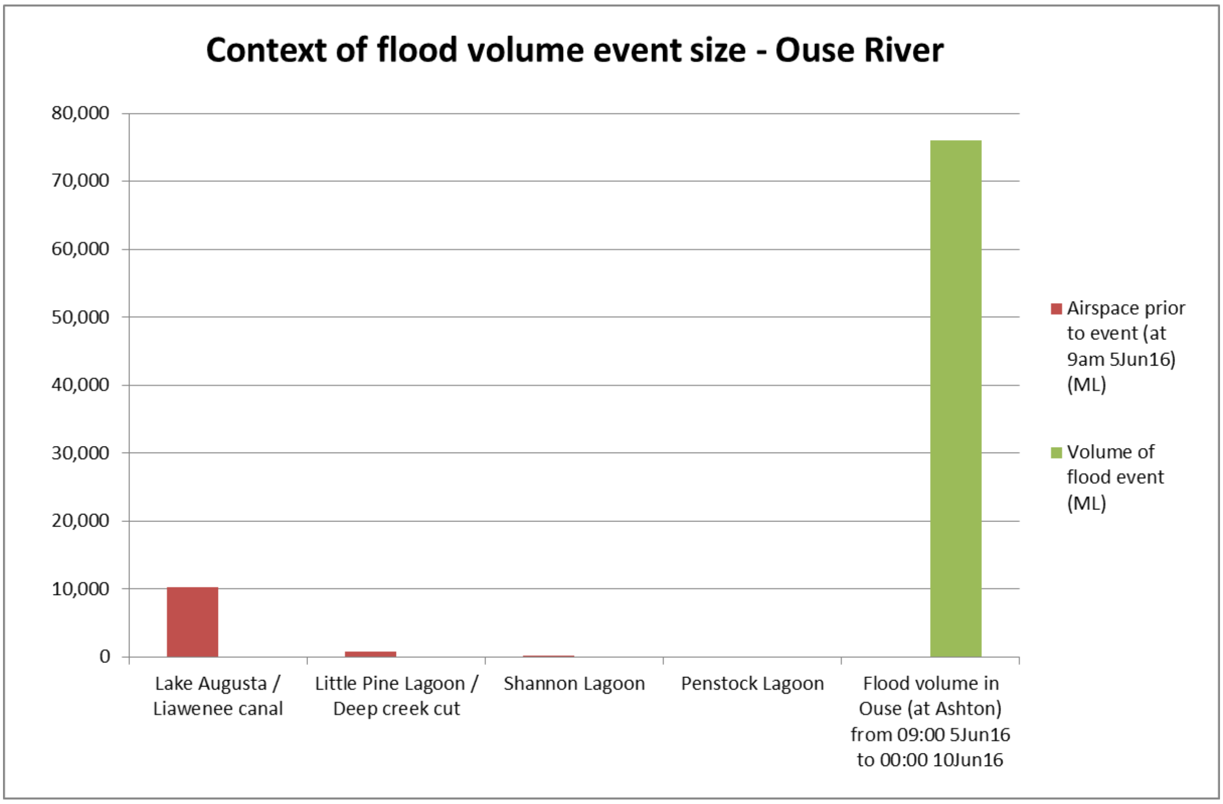
---

[14] All measurements are in metres above sea level.

[15] A storage's Normal Minimum Operating Level (NMOL) is determined by the lowest level at which the civil infrastructure design allows the power station to operate. There are additional operational limits that may also exist to ensure compliance with a number of other obligations including environmental, recreational, licenses, irrigation environmental, recreational and community considerations and requirements.

(c) There was also rainfall in other areas of the catchment, and the small storages of Shannon Lagoon and Penstock Lagoon also filled and spilled, with a negligible spill flowing from those storages through to the River Ouse.[16] Local pick up from rainfall throughout the rest of the catchment would also have contributed to water in the River Ouse.

(d) The following chart provides some context of the volume of water in comparison to the airspace in the relevant storages prior to the flood event.[17]



(e) In the River Ouse a volume of 75,952 ML flowed (measured at Ashton) during the period 09:00 on 5 June 2016 to 00:00 on 10 June 2016.[18] In comparison and contrast, the Lake Augusta airspace prior to the flood event was 10,280 ML.

(f) Prior to the construction of the dams at Miena the water flows from Great Lake would have flowed down the Shannon River into the River Ouse. During the June flood no water was released from Great Lake into the River Ouse

---

[16] See the peak spill figures in table E in the annexure.

[17] Peak data of flood volume was estimated using surveys due to an instrument failure during the event.

[18] Peak data of flood volume was estimated using surveys due to an instrument failure during the event.

catchment.

Ouse – Conclusion

(a) Hydro Tasmania’s actions in the period leading up to and during the June 2016 floods did not increase the volume of water that would otherwise have flowed down the River Ouse, and in fact their operations *reduced* the volume of water. Water was transferred *away* from the River Ouse to Great Lake (via Liawenee canal) and to Lake Echo (via Montpeelyata canal) and neither of those large storages spilled during the floods.

4.4 Operations in the Mersey River System

Mersey - Overview

(a) The Mersey River starts below Mount Rogoona (at an elevation of 948m)[19] and flows in a northerly direction through Rowallan Lake (at 488m) and Lake Parangana (at 381m), and flows past Liena, Kimberley and Latrobe townships on its way to Bass Strait at Devonport.

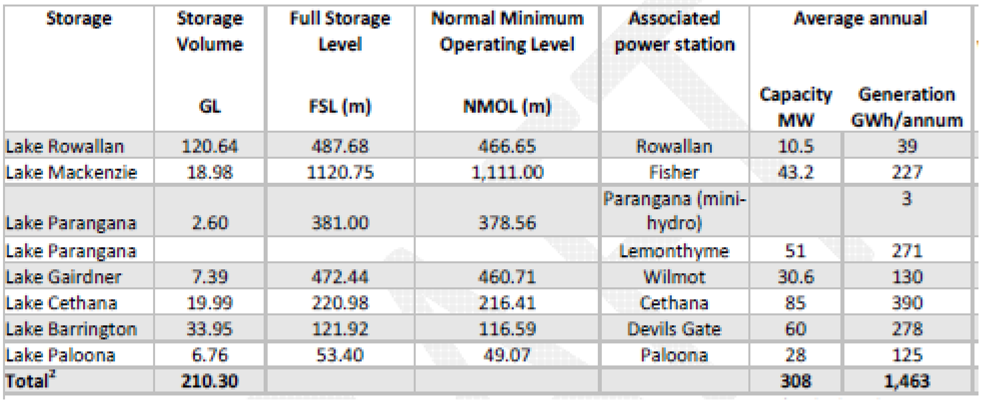
(b) A number of creeks and rivers flow into the Mersey River, including the Arm and Fisher rivers. The Fisher River flows through Lake Mackenzie before it joins the Mersey River.

(c) The Mersey River forms part of the Mersey-Forth system. The Mersey-Forth catchment is in the north-west of Tasmania. It uses water from four main rivers – Fisher, Mersey, Wilmot and Forth. Lakes high in the Western Tiers feed the rivers below and in turn the power stations.

(d) The Mersey-Forth hydro scheme is a run-of-river system. The Mersey Forth catchment has a combined area of 2,800 km$^{2.}$. The following table sets out the storages and associated power stations in the Mersey-Forth catchment:

---

[19] All heights are described as metres above sea level



Storage	Storage Volume GL	Full Storage Level FSL (m)	Normal Minimum Operating Level NMOL (m)	Associated power station	Average annual Capacity MW	Average annual Generation GWh/annum
Lake Rowallan	120.64	487.68	466.65	Rowallan	10.5	39
Lake Mackenzie	18.98	1120.75	1,111.00	Fisher	43.2	227
Lake Parangana	2.60	381.00	378.56	Parangana (mini-hydro)		3
Lake Parangana				Lemonthyme	51	271
Lake Gairdner	7.39	472.44	460.71	Wilmot	30.6	130
Lake Cethana	19.99	220.98	216.41	Cethana	85	390
Lake Barrington	33.95	121.92	116.59	Devils Gate	60	278
Lake Paloona	6.76	53.40	49.07	Paloona	28	125
Total[2]	**210.30**				**308**	**1,463**

(e) The Mersey River flows through Lake Rowallan (and the Rowallan power station), and Lake Parangana (and the Parangana mini hydro), whilst the Fisher River flows through Lake Mackenzie (and the Fisher Power Station), before it flows into Lake Parangana.

(f) A map and schematic of the Mersey-Forth catchment is included at Annexure B.

Mersey - Operation of Hydro Tasmania's assets prior to the floods

(a) The power stations in the Mersey associated with Lake Rowallan (Rowallan Power Station), Mackenzie (Fisher Power Station) and Parangana (Lemonthyme Power Station) were operated prior to the June floods to draw down storages in anticipation of rainfall.

(b) At 9am on 5 June 2016, the levels of Lake Rowallan, Lake Mackenzie and Lake Parangana were:[20]

Lake	**Lake level**	**Full level**	**NMOL**
Lake Rowallan	486.78	487.68	466.65
Lake Mackenzie	1119.94	1120.75	1111.00
Lake Parangana	380.65	381.00	378.56

---

[20] All measurements are in metres.

Mersey - Operation of Hydro Tasmania's assets during the floods

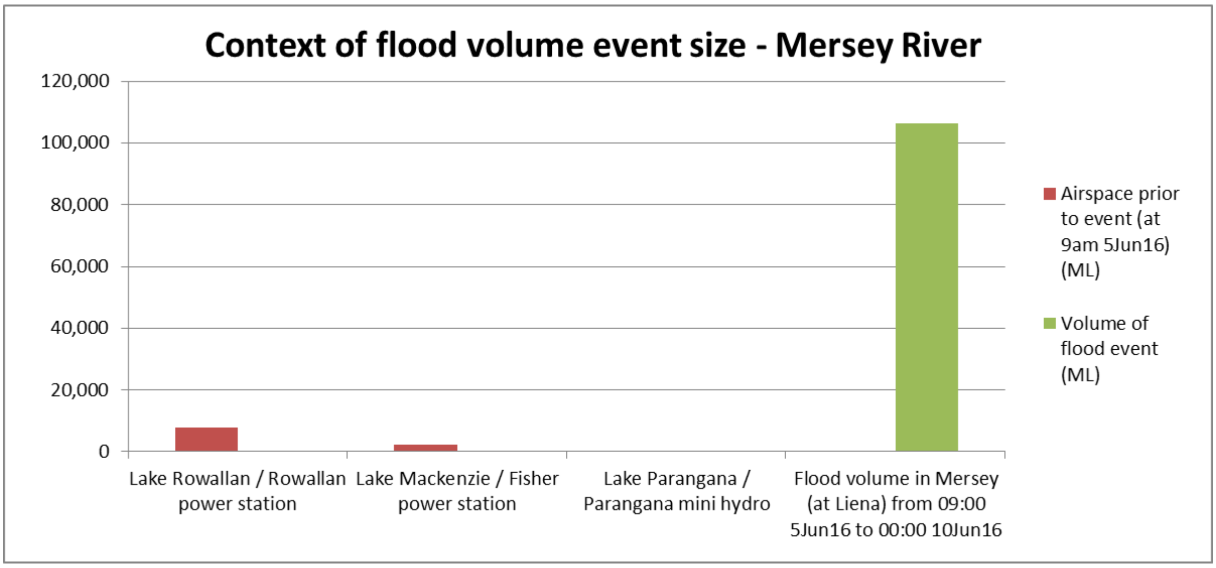
(a) During the June 2016 floods, northern Tasmania received unprecedented rainfall, and all seven lakes in the Mersey-Forth catchment spilled, as the volume of inflows significantly exceeded the capacity of the lakes.

(b) The table in Annexure E sets out the details of when each lake spilled and ceased spilling, the duration on spill, and the peak flow over the spillway.

(c) While the dams at Lakes Rowallan, Mackenzie and Paragana were spilling, the Fisher Power Station (Lake Mackenzie), Rowallan Power Station (Lake Rowallan) and Lemonthyme Power Station (Lake Parangana) generally continued to operate when not unavailable (due to local plant issues associated with the floods). The operation of these power stations once the lakes were spilling did not impact the flow down the Mersey as the water used would otherwise have spilled over the top of the dam's spillway in an uncontrolled manner.

(d) The operation of the Lemonthyme power station reduced the water flowing down the Mersey River as the water was diverted into the Forth River via a tunnel.

(e) The following chart shows the small size of the airspace in the relevant storages prior to the flood event in comparison with the volume of water experienced during these floods.



(f) In the Mersey River a volume of 106,439 ML flowed (at Liena) during the period 09:00 on 5 June 2016 to 00:00 on 10 June 2016.[21]

(g) Due to the high inflows in the preceding month of May 2016, the available air space in Lake Rowallan was only 7,900 ML. It was drawn down, in accordance with SOR, in the five to six days prior to the floods.

Mersey - Conclusion

(a) There are three dams upstream of Latrobe, each of which reached its capacity and spilled during the June 2016 floods. None of these dams have operable spillways which could be used to manage releases.

(b) Once the dams were full, the water that flowed in, flowed out either over the spillways and/or through the associated power stations. Operation of these power stations during the floods did not create any additional water flow towards the town of Latrobe.

(c) The operation of Lemonthyme power station reduced water flow towards Latrobe as it diverted water to the Forth River.

4.5 Operations in the Forth River system

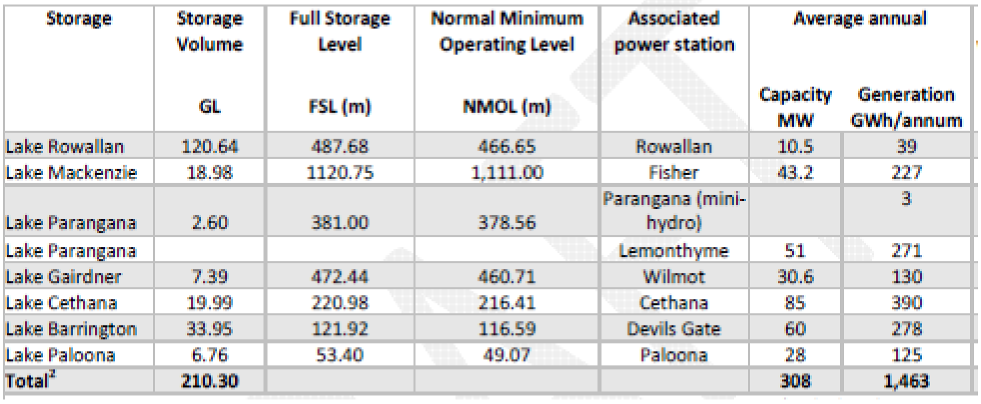
Forth - Overview

(a) The Forth River forms part of the Mersey-Forth catchment. Like the Mersey River, it rises on the central plateau and flow northwards to the coast near Devonport. The majority of the Forth catchment is upstream of Paloona Dam, with the remainder being downstream of hydro generation infrastructure. A number of creeks and rivers flow into the Forth River, including the Wilmot River.

(b) The Forth hydro scheme is a “run of river” system, made up of small storages which fill and spill quickly. The following table sets out the storages and associated power stations in the Mersey-Forth catchment:

---

[21] Post event gauging indicates that the rating curve at Mersey at Liena was underestimating by approximately 25%, meaning the flood volume would actually be higher than this figure, and higher than indicated on the graph.



Storage	Storage Volume GL	Full Storage Level FSL (m)	Normal Minimum Operating Level NMOL (m)	Associated power station	Average annual Capacity MW	 Generation GWh/annum
Lake Rowallan	120.64	487.68	466.65	Rowallan	10.5	39
Lake Mackenzie	18.98	1120.75	1,111.00	Fisher	43.2	227
Lake Parangana	2.60	381.00	378.56	Parangana (mini-hydro)		3
Lake Parangana				Lemonthyme	51	271
Lake Gairdner	7.39	472.44	460.71	Wilmot	30.6	130
Lake Cethana	19.99	220.98	216.41	Cethana	85	390
Lake Barrington	33.95	121.92	116.59	Devils Gate	60	278
Lake Paloona	6.76	53.40	49.07	Paloona	28	125
Total[2]	**210.30**				**308**	**1,463**

(c) The Forth River flows through Lake Cethana (and Cethana Power Station), Lake Barrington (and Devils Gate Power Station), Lake Paloona (and Paloona Power Station) and then continues downstream. The River Iris and River Lea flow into Lake Gairdner then through to Wilmot River or alternatively through Wilmot Power Station into Lake Cethana. Water from Lake Parangana in the Mersey is transferred into Lake Cethana via the Lemonthyme tunnel and Power station.

(d) The map and Schematic of the Mersey-Forth catchment are included in Annexure B.

Forth - Operation of Hydro Tasmania's assets prior to the floods

(a) The power stations in the Forth were operated prior to the June floods to draw down storages in anticipation of rainfall.

(b) At 9am on 5 June 2016, the levels of the lakes were:[22]

Lake	Lake level	Full level	NMOL
Lake Paloona	52.56	53.34	49.07
Lake Barrington	121.17	121.92	116.59
Lake Cethana	217.23	220.98	216.41
Lake Gairdner	468.06	472.44	460.71

Forth - Operation of Hydro Tasmania's assets during the floods

---

[22] All measurements are in metres above sea level.

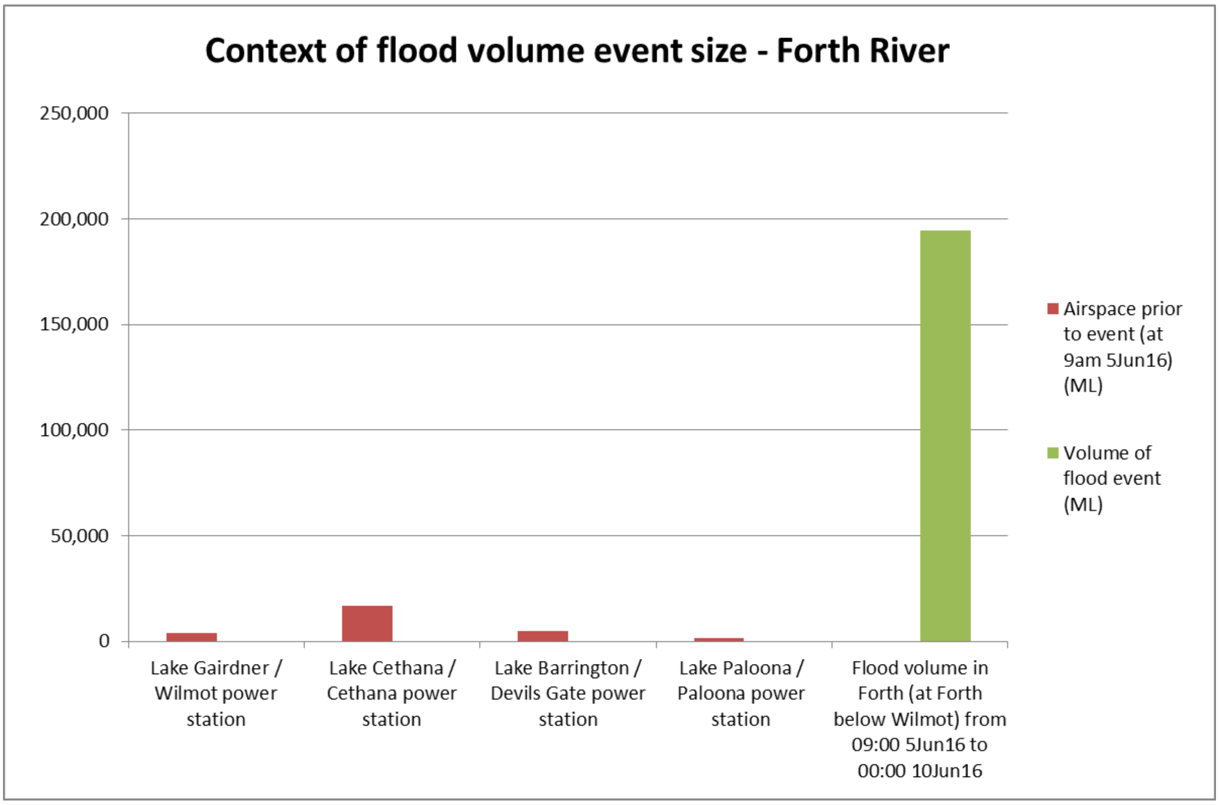
(a) During the June 2016 floods northern Tasmania received unprecedented rainfall, and all seven lakes in the Mersey-Forth catchment spilled, as the volume of rainfall that fell significantly exceeded the capacity of the lakes.

(b) While the dams were spilling, the Wilmot, Cethana, Devils Gate and Paloona power stations continued to operate. The operation of these power stations once the lakes were spilling did not increase flood flow down the Forth River as the water used would otherwise have spilled over the top of the dam's spillway in an uncontrolled manner.

(c) The Lemonthyme Power Station at Lake Parangana also continued to operate once Lake Parangana was spilling. It diverted water from the Mersey to the Forth (thereby reducing flood flows in the Mersey but increasing flood flows in the Forth). The water was transferred in order to make best use of it for energy generation, in circumstances where both catchments were flooding and it was not possible to anticipate which valley would have more significant floods. The maximum flow of water via Lemonthyme tunnel was $44m^3/s$ (cubic metres per second), which is small in the scheme of the floods (this can be compared to the peak flow of $800m^3/s$ which flowed over the spillway at Lake Paloona, the final dam in the Forth River).

(d) The operation of the Wilmot Power Station at Lake Gairdner transferred water from the Wilmot River into the Forth River. However, in any event, spill from Lake Gairdner flows into the Wilmot River which then joins the Forth River downstream of Lake Paloona (upstream of the town of Forth). Hence operation of the Wilmot power station did not impact the volume of water that flowed towards the town of Forth.

(e) The following chart provides some context of the airspace in the respective storages in the Forth in comparison to the volume of water in these floods.



(f) In the Forth River a volume of 194,580 Mega Litres (ML) flowed (at Forth below Wilmot) during the period 09:00 on 5 June 2016 to 00:00 on 10 June 2016. In comparison and contrast, the storage on the Forth River with the greatest airspace prior to the flood event was Cethana with an airspace of 16,630 ML.

Forth – Conclusion

(a) Hydro Tasmania's actions in the period leading up to and during the June 2016 floods marginally increased the volume of water that flowed down the Forth River, as water was transferred from the Mersey to the Forth via Lemonthyme Tunnel. However, this water would have otherwise added to flooding in the Mersey.

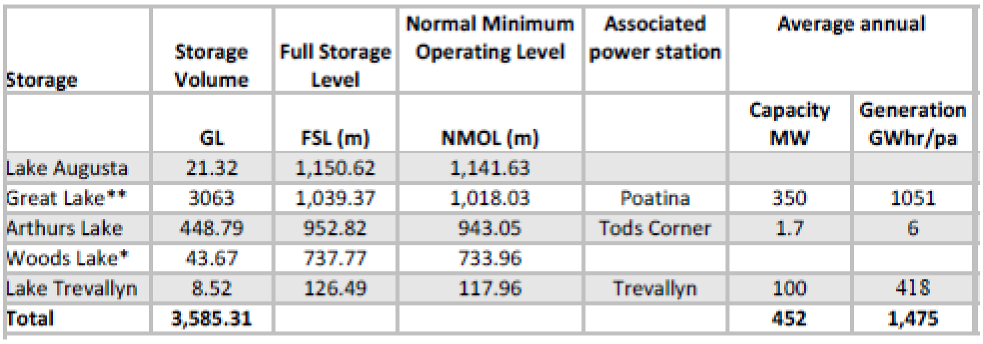
(b) Hydro Tasmania's actions did not otherwise increase the volume of water in the Forth River, and did provide some mitigation through the attenuation effect due to drawing down storages prior to flooding. None of these dams have operable spillways which could be used to release flood waters.

4.6 South Esk

South Esk - Overview

(a) The greater South Esk River catchment is the largest water catchment area in Tasmania, making up almost 15% of Tasmania's land mass, covering an area of almost 9,000 km2. Its major rivers are the South Esk, Macquarie, and Meander Rivers. The North Esk and South Esk Rivers both flow into the head of the River Tamar within 1 kilometre of each other.

(b) Hydro Tasmania's storages that feed its hydro power stations in the South-Esk Great Lake hydro catchment are as follows:



Storage	Storage Volume	Full Storage Level	Normal Minimum Operating Level	Associated power station	Average annual	
	GL	FSL (m)	NMOL (m)		Capacity MW	Generation GWhr/pa
Lake Augusta	21.32	1,150.62	1,141.63			
Great Lake**	3063	1,039.37	1,018.03	Poatina	350	1051
Arthurs Lake	448.79	952.82	943.05	Tods Corner	1.7	6
Woods Lake*	43.67	737.77	733.96			
Lake Trevallyn	8.52	126.49	117.96	Trevallyn	100	418
Total	**3,585.31**				**452**	**1,475**

*Woods Lake is primarily used as storage for Hydro Tasmania to meet irrigation water supply obligations along the Lake River

**Great Lake is physically located in the Derwent hydro-electric district, however the water is used in the South Esk hydro-electric district.

(c) With respect to the rivers that suffered flooding during the June 2016 Floods:

(i) The South Esk River enters Lake Trevallyn / Trevallyn Dam from which the water can either pass via the power station or Cataract Gorge into the River Tamar. The Lake River starts at Arthurs Lake and passes via Woods Lake into the Macquarie River, which joins the South Esk River. Neither of Arthurs Lake or Woods Lake spilled during the flood event, and did not contribute any water to the flood flows.

(ii) Poatina Power Station (which takes its water from the Great Lake) discharges into Brumby's Creek, which flows into the Macquarie River.

(iii) The Meander River starts below Bastion Bluff and runs for 112km before merging with the South Esk River immediately above Lake

Trevallyn. Hydro Tasmania does not have any dams on the Meander River.

(iv) Hydro Tasmania does not have any dams or relevant infrastructure on the North Esk River. The North Esk River also experienced severe flooding during the June floods, contributing to water flow in the Tamar.

(d) As can be seen from above, water from the Macquarie River, Meander River, Upper Lake, Lake Rivers and Brumby's Creek (via the Macquarie River) and South Esk River all ultimately flow through to Trevallyn Lake and Trevallyn Dam. Lake Trevallyn has very little storage.

(e) As previously discussed in section 4.3(f), although Great Lake is located in the natural Derwent catchment area, it supplies water to Poatina Power Station in the South Esk. Great Lake captured rainfall during the floods and its level rose but it did not spill, and did not contribute any water to flood flows.

(f) A map and schematic showing the Great Lake / Trevallyn Power Scheme is included at Annexure D.

South Esk - Operation of Hydro Tasmania's assets prior to the floods

(a) Trevallyn Power Station was operated prior to the June floods to draw down Lake Trevallyn in anticipation of high inflows.

(b) Poatina Power Station was not operated in the days prior to the June 2016 floods as there was sufficient generation capacity available at other spilling storages to meet the Tasmanian electricity demand.

(c) At 9am on 5 June 2016, the levels of Lake Trevallyn, Poatina Re-regulation Pond, Great Lake and Woods Lake were:[23]

Lake	**Lake level**	**Full level**	**NMOL**
Lake Trevallyn	118.75	126.49	117.96
Poatina Re-Regulation Pond	156.53	157.50	155.00

---

[23] All measurements are in metres.

Great Lake[24]	1022.48	1039.37	1018.03
Woods Lake[25]	735.94	737.77	733.96

South Esk - Operation of Hydro Tasmania's assets during the floods

(a) During the June 2016 floods, there was a sudden and significant increase in flows in the South Esk river and its tributaries as a result of high rainfall.

(b) Consistent with the Storage Operating Rules Poatina Power Station did not operate during the June 2016 floods in order to prevent adding to flood flows.

(c) A small water volume was gradually discharged from the Poatina Regulation Pond, in order to prevent a larger sudden automatic discharge which would have otherwise been required to protect the dam. This water was run off from the area next to the canal and was not from the power station.

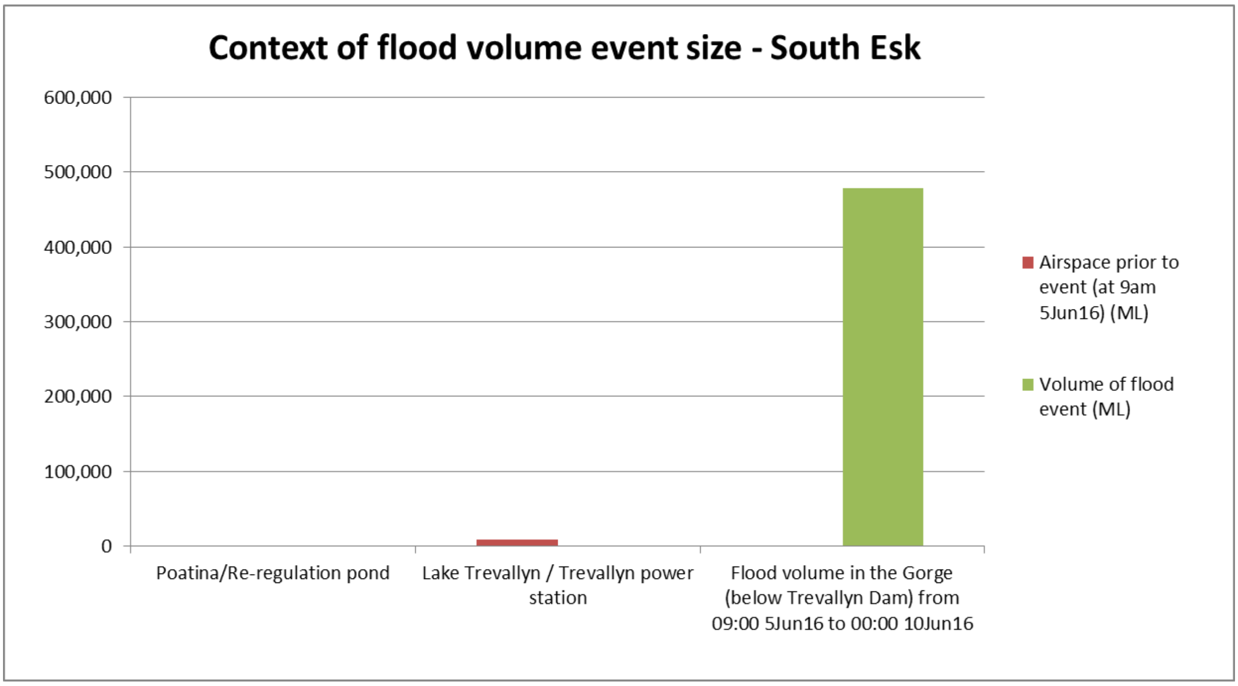
(d) The water level at Lake Trevallyn quickly increased on 6 June 2016 due to significant rainfall in the South Esk catchment during the course of the floods, leading to Lake Trevallyn spilling on 6 June 2016. The power station continued to operate during the floods, however this did not impact on the volume of water as that water simply ran through the power station rather than over the spillway.

(e) The following chart shows the small size of the airspace in the respective storages prior to the flood event in comparison with the volume of water experienced during these floods.

---

[24] Did not spill or release water

[25] Did not spill or release water



(f) In the Cataract Gorge (below Trevallyn Dam) a volume of 478,684 ML flowed (into the River Tamar) during the period 09:00 on 5 June 2016 to 00:00 on 10 June 2016. Upstream, the Trevallyn Dam had an airspace of 8,010 ML and it was drawn down as far as reasonably possible in the days prior to the flood event.

South Esk – Conclusion

(a) Hydro Tasmania's actions in the period leading up to and during the June 2016 floods did not increase the volume of water that would otherwise have flowed through to Trevallyn Dam and Launceston, apart from releasing a negligible amount of water from Poatina Re-Regulation pond in order to prevent a larger sudden automated release.

(b) The operation of Trevallyn Power Station prior to the floods had the effect of drawing down Lake Trevallyn, which had the effect of only slightly reducing the flood.

ANNEXURE A

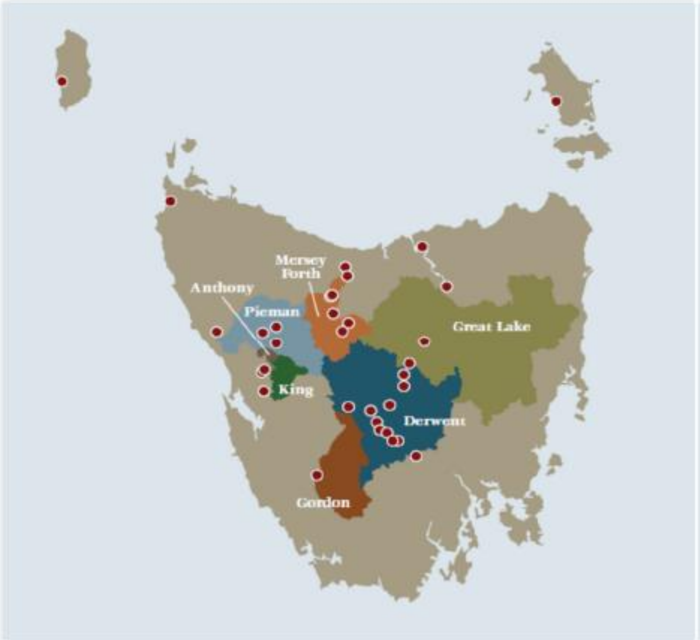
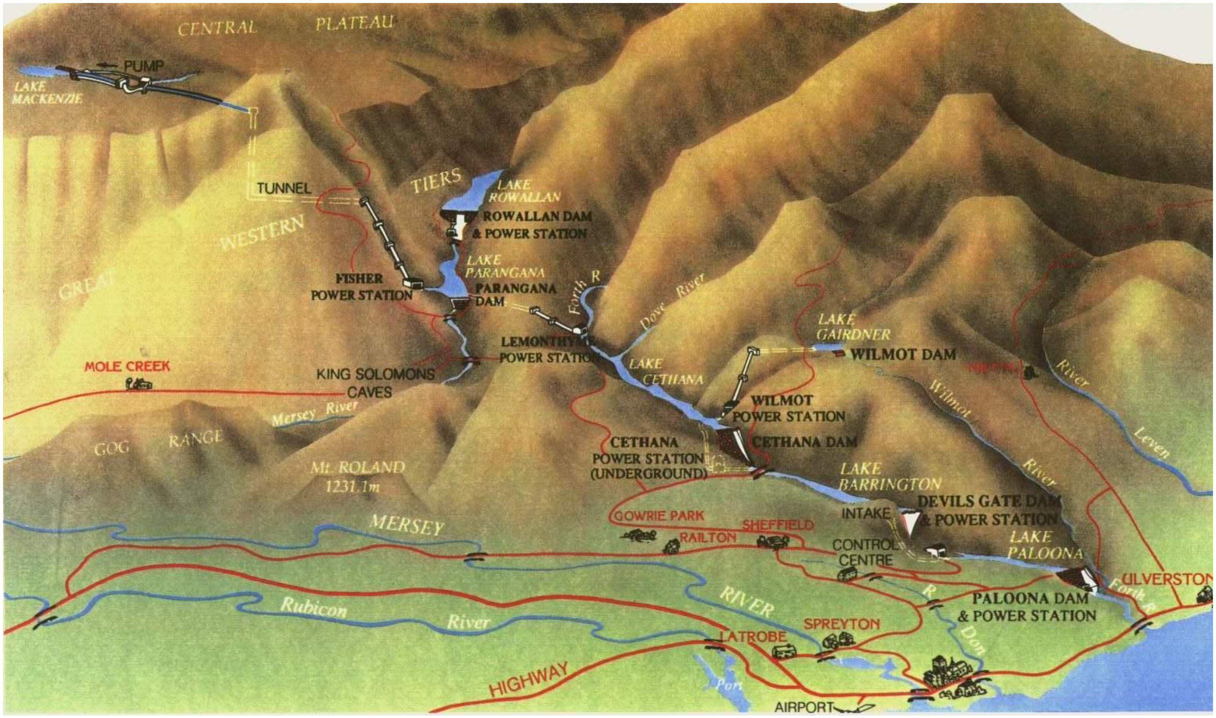


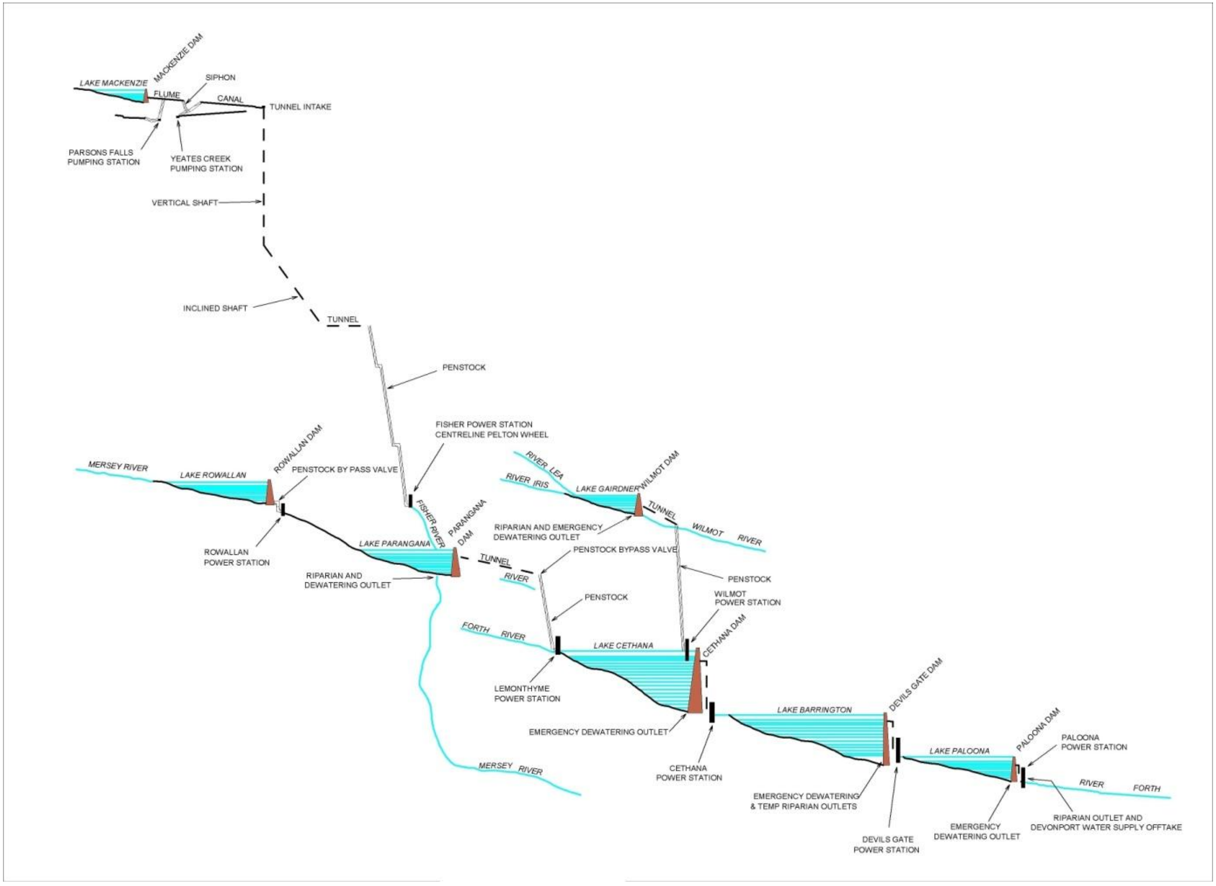
Figure 1: Major Storage Catchments and Power Stations in Tasmania

ANNEXURE B

Mersey-Forth Scheme map

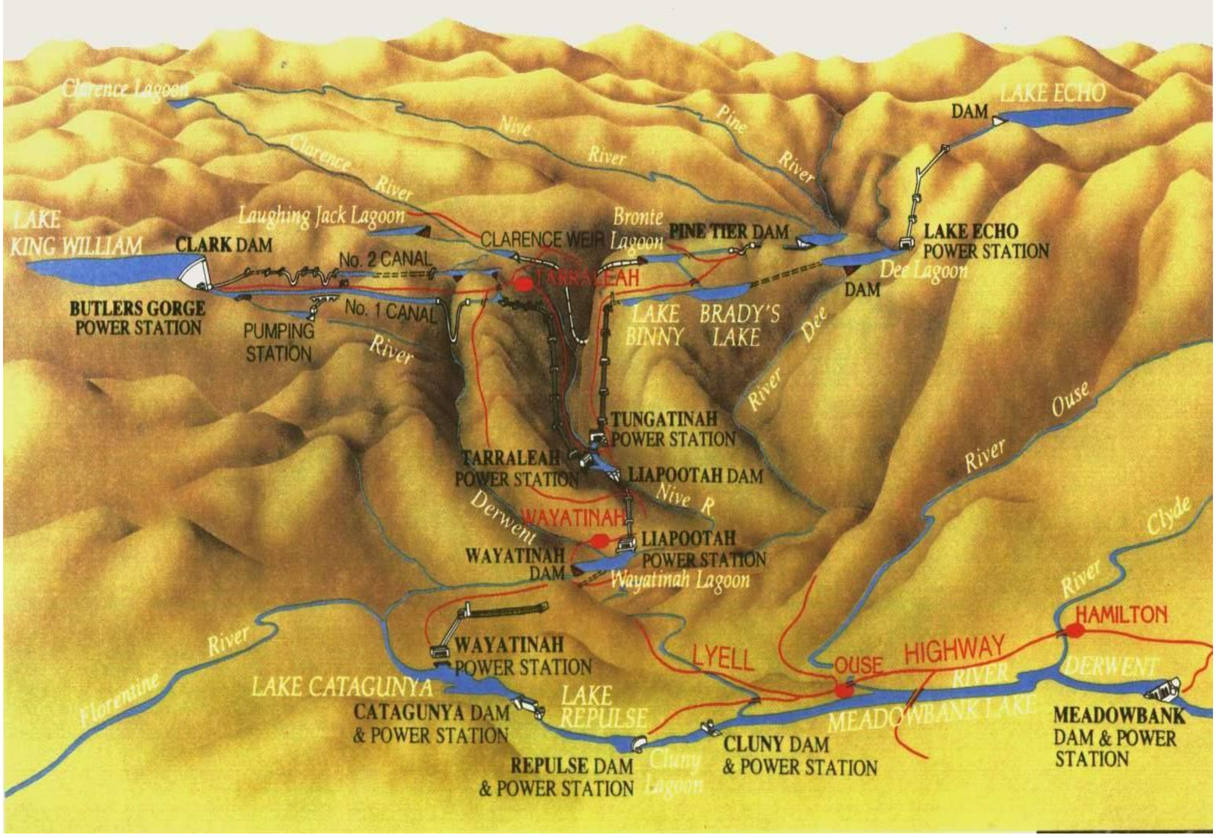


Mersey Forth Scheme schematic

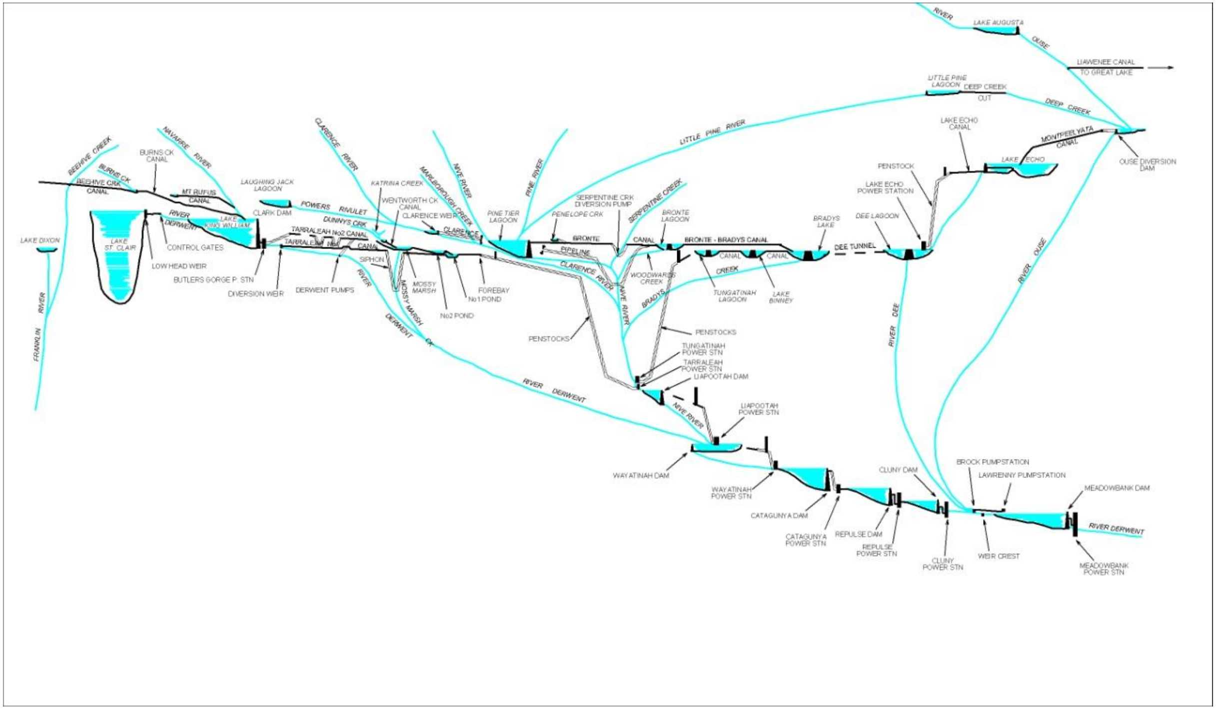


ANNEXURE C

Upper and Lower Derwent Scheme (including the River Ouse) map

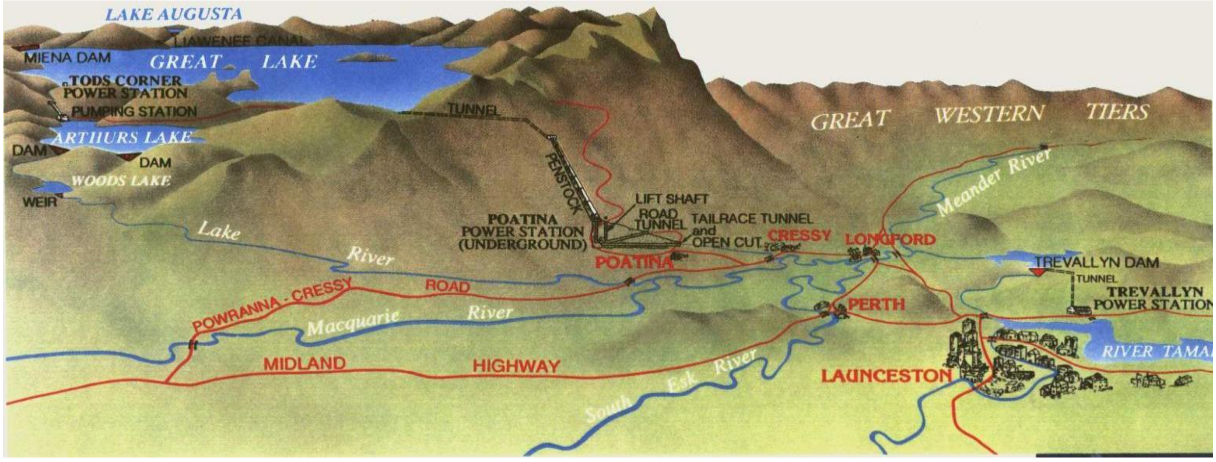


Upper and Lower Derwent Scheme (including the River Ouse and Lake Augusta) schematic

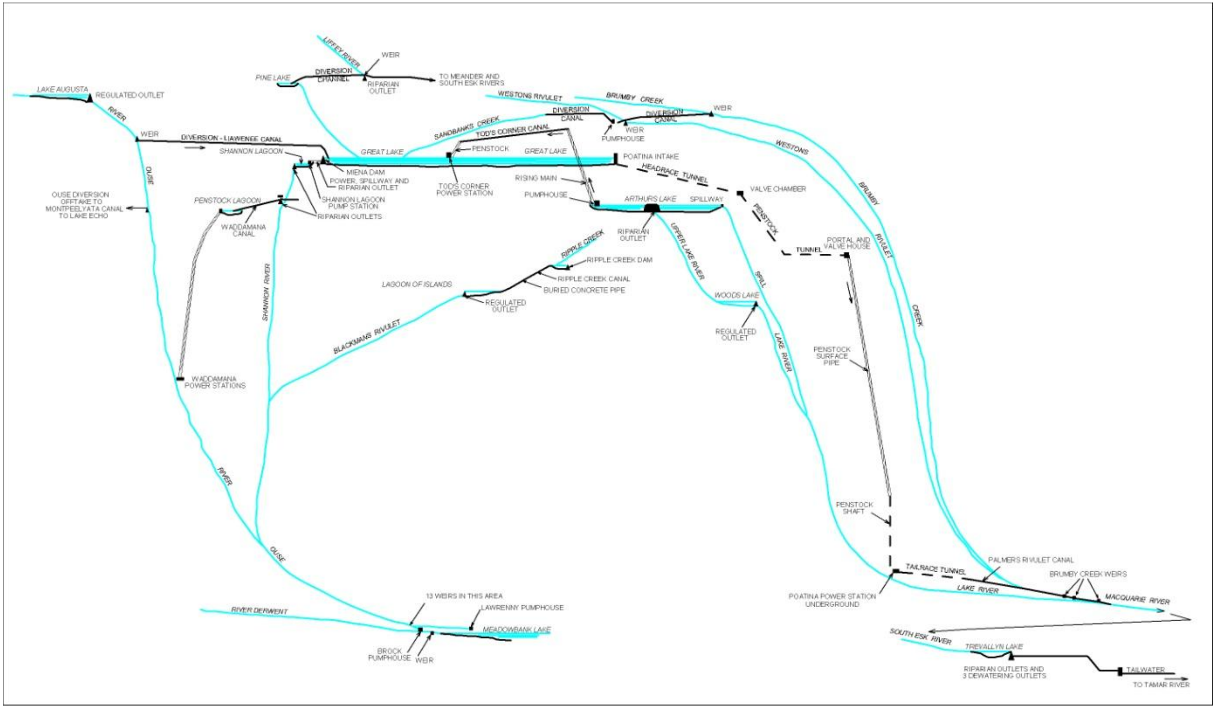


ANNEXURE D

South Esk / Great Lake Scheme (including Trevallyn) map



South Esk / Great Lake Scheme (including Trevallyn) schematic



ANNEXURE E

Storage	**Date/Time on Spill**	**Date/Time off spill**	**Duration on spill (hours)**	**Peak Flow (cumecs)**[26]	**Comment**
Affecting the Mersey					
Lake Rowallan	6/06/2016 0:10	17/06/2016 18:10	282	128	
Lake Mackenzie	5/06/2016 13:35	13/06/2016 15:30	194	286.6	
Lake Parangana	5/06/2016 9:25	19/06/2016 15:00	342	912.1	Note returned to spill shortly after this ~ 1 day later, and spilled with a few brief dips below FSL until 29/08/2016
Affecting the Forth					
Lake Gairdner	5/06/2016 12:40	13/06/2016 20:35	200	430.2	
Lake Cethana	5/06/2016 17:15	15/06/2016 18:00	241	770.1	
Lake Barrington	5/06/2016 19:20	21/06/2016 22:05	387	807.7	
Lake Paloona	6/06/2016 0:30	22/06/2016 11:55	395	800.8	Note returned to spill shortly after this ~ 1 day later, and has been largely spilling since with a few brief (up to 2 days) dips below FSL
Affecting the Ouse					
Lake Augusta	5/06/2016 16:45	14/06/2016 12:30	212	487.6	
Little Pine Lagoon (relevant because of Deep creek cut)	6/06/2016 0:45	20/06/2016 13:45	349	70.78	Little Pine Lagoon spills into the Little Pine River and then reaches the Nive River, so does not enter the River Ouse
Monpeelyata Weir	5/06/2016 13:00	11/06/2016 12:00	143	559.6	
Shannon Lagoon	5/06/2016 23:00	19/06/2016 22:30	335	8.11	
Penstock Lagoon	6/06/2016 5:00	2/07/2016 12:15	631	0.78	
Great Lake	Did not spill				
Affecting the South Esk					
Woods Lake	Did not spill				

---

[26] The peak flow is the water flow over the spillway of the dam, measured in cubic metres per second ('cumecs')

Storage	Date/Time on Spill	Date/Time off spill	Duration on spill (hours)	Peak Flow (cumecs)[26]	Comment
Great Lake	Did not spill				
Poatina Re-regulation pond	5/06/2016 19:40	7/06/2016 10:40	39	46.43[27]	Time of release above 2 cumecs. Also released up to ~4 cumecs on the 4/6/16
Lake Trevallyn	6/06/2016 13:45	17/06/2016 9:50	260	2376	

---

[27] The peak flow value for Poatina re-regulation pond is discharge rather than spill.

TERM OF REFERENCE 3: CLOUD SEEDING

*The causes of the floods which were active in Tasmania over the period 4-7 June 2016 including **cloud-seeding**, State-wide water storage management and debris management.*

1 CAUSE OF THE FLOODS

(a) It is clear that the direct cause of the flooding that affected northern Tasmania (including the Mersey, Forth, Ouse and South Esk rivers) during the relevant period was caused by "*a persistent and very moist north-easterly airstream*" which resulted in "*daily* [rainfall] *totals* [that were] *unprecedented for any month across several locations in the northern half of Tasmania*", in some cases in excess of 200mm.[1]

(b) This paper addresses the Hydro Tasmania cloud seeding flight of 5 June and outlines the conclusion, supported by expert analysis, that it did not cause or contribute to the floods.

2 CLOUD SEEDING

2.1 Overview

(a) Between 10.57am and 12.31pm (1 hour and 34 minutes) on 5 June 2016, Hydro Tasmania conducted a cloud seeding operation over the Western Tiers, just north of Great Lake.

(b) Hydro Tasmania understands community concern about the possibility that the 5 June 2016 flight may have contributed to the flood event.

(c) Significant analysis was undertaken using data from the flight, and findings were published in a report provided to the Government, and released publicly, on 29 July 2016.

(d) That report concludes that the cloud seeding operation had no measurable impact on rainfall on 5 June 2016 because the cloud that was seeded already contained significant ice and was already precipitating freely.

(e) A copy of that report is attached at annexure A.

---

[1] Bureau of Meteorology's Special Climate Statement 57, issued on 17 June 2016.

2.2 Background to seeding operation

(a) Hydro Tasmania brought forward the start of its cloud seeding season this year as part of efforts to rebuild storages, which were low following an unprecedented dry Spring and Summer and the then current Basslink outage (which later ended on 13 June 2016).

(b) The flight was undertaken both as part of Hydro Tasmania's usual practice of seeking to enhance rainfall over hydro catchments and also having regard to the need for storage recovery given those circumstances.

(c) The decision to undertake the 5 June 2016 cloud seeding flight had regard to water levels in key Hydro Tasmania storages, the forecast weather conditions on the day and the flood warnings issued by the Bureau of Meteorology (BoM).

(d) The operation was undertaken with the intent of enhancing rainfall into hydro storages in the Upper Derwent catchment (including Lake Echo, which was still below its preferred level at that time). Had the seeding flight been successful it was possible there would also have been an effect in the Great Lake catchment, Arthurs Lake and Woods Lake.

(e) There were no flood warnings in place in the Upper Derwent or Great Lake catchments at the time of the flight.

(f) Cloud seeding began at 10:57am, in seeding conditions that were described on the Flight Log as "marginal", and continued for 1 hour and 34 minutes to 12:31pm.

2.3 The impact of seeding

(a) Post-flight analysis of data has shown that the cloud seeding operation had no measurable effect on rainfall on 5 June 2016.

(b) Data collected by the aircraft's instruments and data obtained from the BoM, and analysed post-flight, show the cloud that was seeded on 5 June 2016 already contained significant ice and was already precipitating freely, meaning that in those particular circumstances, any seeding effort to initiate precipitation was redundant.

2.4 Expert analysis by Associate Professor Steven Siems of Monash University

(a) Associate Professor Steven Siems, of Monash University, School of Earth, Atmosphere and Environment *and* School of Mathematical Sciences, has been engaged by Hydro Tasmania to assist it with understanding any impact that the cloud seeding flight had upon rainfall on 5 June 2016 and in the following days.

(b) A/Prof Siems has concluded that the cloud seeding flight undertaken had no measurable impact on precipitation on 5 June 2016 and the following 48 hours.

(c) A/Prof Siems has provided a report dated 8 November 2016. Hydro Tasmania is prepared to disclose that report for the purposes of the Government Flood Review. A copy is attached at annexure B. A copy of A/Prof Siems' curriculum vitae is attached at annexure C.

2.5 Ongoing review

(a) Hydro Tasmania is currently undertaking a review of the cloud seeding program to make improvements in its processes, including in relation to seeding when there is a risk of floods, so that future decisions about cloud seeding are more in line with community expectations.

(b) Hydro Tasmania commenced preliminary consultation with key stakeholder groups in September 2015 including representatives from local councils in municipalities where cloud seeding is undertaken and the Tasmanian Farmers and Graziers Association. Hydro Tasmania is and will continue to actively collect feedback on community concerns in relation to its cloud seeding program from key stakeholder groups.

(c) The initial feedback collected since September this year has been used to scope the cloud seeding review process that is currently underway.

(d) Previous reviews of the cloud seeding program were conducted in 2002 and 2008 in collaboration with key stakeholders in response to community concerns and some improvements to the program were made as a result.

(e) Hydro Tasmania's cloud seeding program remains on hold and will not resume until the review of the program has been completed, including extensive stakeholder consultation, and any appropriate improvements have been implemented.

Hydro
Tasmania
The power of natural thinking

Cloud seeding flight of 5 June 2016

Background and event final report

29 July 2016

Contents

Statement of Purpose

This report has been prepared by Hydro Tasmania for the purpose of advising the Minister for Energy of the background to, and impact of, the cloud seeding flight that Hydro Tasmania undertook on 5 June 2016.

Executive Summary

Between 5 to 9 June 2016, Tasmania was affected by an extreme weather event that caused major flooding in Tasmania, including in the South Esk, Ouse, Mersey and Forth rivers. Unprecedented rainfall occurred over a significant time and geographical area.

Between 10.57am and 12.31pm (1 hour and 34 minutes) on 5 June 2016, Hydro Tasmania conducted a cloud seeding operation over the Western Tiers, just north of Great Lake.

The operation was undertaken with the intent of enhancing rainfall into the Hydro storages in the Upper Derwent catchment (including Lake Echo). Had the seeding flight been successful it is possible there would also have been an effect in the Great Lake catchment, Arthurs Lake and Woods Lake. The operation took account of issued flood warnings and the Bureau of Meteorology forecasts.

The glaciogenic cloud seeding employed by Hydro Tasmania operates by introducing ice nuclei to clouds with high levels of super-cooled liquid water and low or no ice content, with the aim of converting the super-cooled liquid water droplets to ice, which will then fall as precipitation (rain or ice crystals).

Analysis of all available information concerning the cloud seeding operation has determined that the operation had no measurable impact on rainfall on 5 June 2016. The cloud that was seeded on 5 June 2016 already contained significant ice and was already precipitating freely, meaning that any seeding effort to initiate precipitation was redundant.

Background to Seeding Operation

Cloud seeding program at Hydro Tasmania

Hydro Tasmania has been involved with experimental and operational cloud seeding since 1964, and in its current format since 1999.

The program generally operates over the late autumn (May) to spring (end October) each year ("seeding season"), as this is considered to be the period when the most suitable conditions exist for effective cloud seeding.

The objective of the program is to enhance rainfall in hydro catchments.

Energy supply challenge

The sustained and record low inflows to hydro storages over the 2015-16 spring / summer and the extended forced outage of Basslink that commenced on 20 December 2015 (and concluded on 13 June 2016) required a major response by Hydro Tasmania to ensure continuation of supply to the Tasmanian electricity system.

The primary response came through the Energy Supply Plan which involved maximising generation output from gas-fired turbines at the Tamar Valley Power Station, voluntary load reductions agreed commercially with major industrial customers and installing approximately 220 MW of temporary diesel generation.

An additional response by Hydro Tasmania was to commence the cloud seeding program on 1 April, a month earlier than planned.

Catchment targeting

Initially all hydro catchments were targeted at the commencement of the 2016 cloud seeding season, reflecting the low hydro storage position in early April.

On 12 May 2016, the hydro catchments of Upper Pieman and Mersey Forth were removed from the target list, due to the strong inflows to hydro storages, and spill occurring at a number of dams (including Lake Parangana on the Mersey River and Lake Paloona, Lake Gairdner, Lake Cethana and Lake Barrington on the Forth River).

At the start of June, the targets for cloud seeding, in order of priority, were identified as the Great Lake, Gordon, and Upper Derwent catchments

Flood warnings applicable to 5 June cloud seeding flight

During the morning of 5 June 2016 and prior to the cloud seeding flight, the following flood warnings had been issued by the Bureau of Meteorology (BoM) and were applicable for Hydro Tasmania's hydro catchments.

Table 1: Status of flood warnings issued prior to and applicable to the cloud seeding flight on 5 June

BoM warning	Time/date last issued	River	Hydro catchment
Moderate	6:45am, 5 June	Mersey River	Mersey-Forth
Moderate	6:54am, 5 June	South Esk River	South Esk
Minor	9:38am, 5 June	Meander River	South Esk
Minor	9:40am, 5 June	Forth River	Mersey-Forth
Moderate	9:54am, 5 June	South Esk River	South Esk
Moderate	10:03am, 5 June	Mersey River	Mersey-Forth
Minor	10:12am, 5 June	Macquarie River	South Esk

There were no flood warnings in effect for the Upper Derwent or Great Lake catchments at the time of the flight.

The seeding operation

The cloud seeding flight of 5 June 2016 took off from Hobart airport at 10:04am and flew northwest to meet the strong north-easterly weather front that was coming down from the Australian continent. The Flight Log records that the Upper Derwent catchment was the primary target area. Had the seeding flight been successful it was possible there would also have been an effect in the Great Lake catchment, Arthurs Lake and Woods Lake.

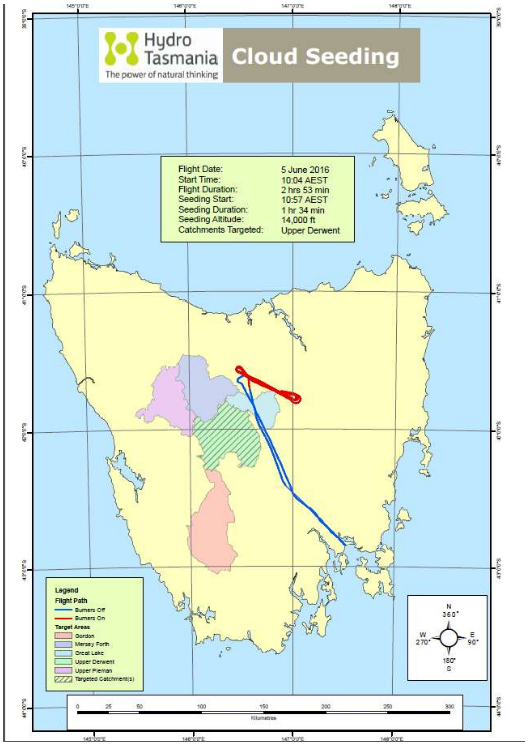
The Flight Log also records that at 10:33am the seeding track was drawn for the Upper Derwent, and located having regard to flood warnings on northern rivers.[1]

The assessment of the suitability of a cloud for seeding can only be undertaken when airborne, as vital parameters (such as supercooled liquid water content, wind speed and direction) must be measured on location, in cloud.

Cloud seeding began at 10:57am, in seeding conditions that were described on the Flight Log as “marginal” with “mixed-phase” clouds[2] and “generally low LWC”(meaning supercooled liquid water content), and continued for 1 hour and 34 minutes, to 12:31pm.

The flight then returned to Hobart airport at 12:57pm.

The flight and seeding track is shown in the figure below.



---

[1] The cloud seeding track is set at least 30 minutes upwind of the desired target catchment, based on CSIRO studies in Tasmania that showed that it takes between 30 and 45 minutes from cloud seeding to precipitation reaching the ground (although a number of factors can affect this period).

[2] Containing a combination of ice and supercooled liquid water.

Hydro Tasmania's decision to undertake the 5 June 2016 cloud seeding flight had regard to water levels in key Hydro Tasmania storages, the forecast weather conditions on the day and the flood warnings issued by the Bureau of Meteorology.

The flight was undertaken as part of Hydro Tasmania's usual practice of seeking to enhance rainfall during the seeding season and having regard to the need for storage recovery following drought and the then current Basslink outage.

The seeding track for the flight was set, taking account of issued flood warnings and the Bureau of Meteorology's forecast wind speeds, to avoid targeting areas subject to flood warnings and to be sufficiently upwind of the target area so that rainfall that might be initiated through seeding would reach the ground at the target.

The Impact of Seeding

Cloud seeding is a physical process which depends on the existence of particular cloud conditions.

Cloud seeding science

The theoretical development of precipitation in non-glaciated (i.e. no ice processes) clouds is well understood:

- Starting with small liquid droplets, the droplets will initially grow through condensation in a saturated environment.
- Once the droplets have grown to a size of roughly 20 microns (μm), the bigger ones will begin to fall relative to smaller droplets.
- Smaller droplets within the path of bigger droplets commonly become collected by the bigger droplets (collision and coalescence), which allows the bigger droplets to grow even more rapidly, fall more rapidly and collect even more smaller droplets.
- Once droplets reach 100 μm in size, they can be said to be precipitating.
- A positive chain reaction is set off that allows the big droplets to grow to sizes of at least 200 μm.

If a cloud consists of small supercooled liquid water droplets, the initial growth by condensation may be relatively slow. Clouds can persist in this state for long periods of time and may not develop to a stage of precipitation.

Glaciogenic cloud seeding is a process of introducing ice nuclei to clouds containing supercooled liquid water. Hydro Tasmania's cloud seeding program utilises an aircraft fitted with a specialised external burner that releases a vaporised silver iodide solution to create the ice nuclei.

In a suitable seeding environment, these ice nuclei will convert the supercooled liquid water into ice crystals. The ice crystals are able to grow efficiently through condensation (often at the expense of the supercooled liquid water). Once the ice crystals are big enough, they will fall relative to the supercooled liquid water droplets. Collision and coalescence will follow, similar to the process that occurs in non-glaciated clouds, and precipitation will follow.

If a cloud is readily precipitating (whether as liquid, ice or mixed phase), the collision and collection process is already underway. Introducing further ice nuclei will not enhance this process.

Even if cloud seeding were to convert some smaller supercooled liquid water droplets into ice, they would still be quite small in comparison to the larger drops/ice crystals that are already present. These larger drops/crystals will continue to collect the smaller droplets/ice crystals, regardless of whether they have begun to aggregate around introduced ice nuclei or not.

Further information about the program, including the science and process of cloud seeding can be found on the Hydro Tasmania website - http://www.hydro.com.au/water/cloud-seeding

Post-flight data analysis

The cloud seeding operation had no measurable impact on rainfall on 5 June 2016 because the cloud was already heavily glaciated (i.e. ice) along the seeding track and precipitation was already present. Thus, adding further ice nuclei did not enhance this process.

Data was collected during the flight which has been subsequently analysed as part of this investigation.

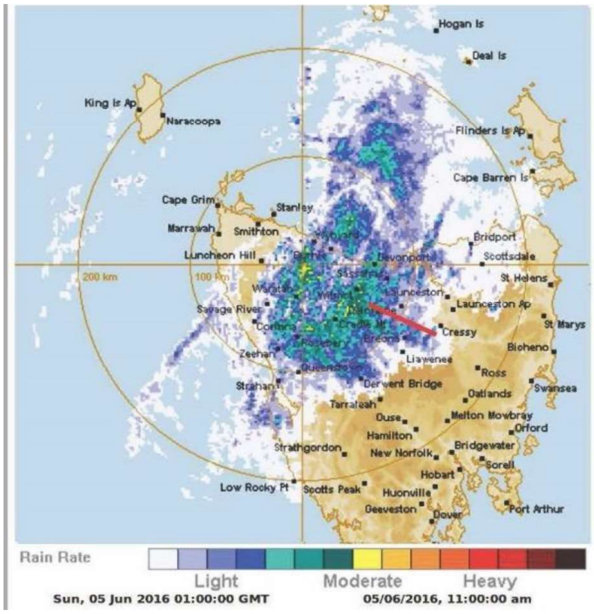
The average total water content (TWC) for the duration of the seeding was 0.39g/kg, and the average liquid water content (from the LWC083 probe) was 0.09 g/kg. On these figures, on average 86% of the total water content in the cloud during seeding was ice. These figures indicate that the seeded clouds were, on average, heavily glaciated (i.e. mostly ice). This is consistent with the airborne observations that the clouds had generally low supercooled liquid water content.

From the aircraft's Cloud Imaging Probe (CIP) of the Cloud Aerosol and Precipitation Spectrometer (CAPS), it is clear that rain-sized droplets and large ice particles were present along the seeding track. These airborne observations are consistent with pre-existing on-ground precipitation and the Bureau of Meteorology's (BoM) ground-based radar observations at West Takone, the Himawari-8 satellite imagery and the BoM's operational weather forecast.

As mentioned above, cloud seeding is intended to work on small supercooled liquid water droplets, generally of size 10 µm or less, whilst drops and crystals above ~100 µm radius are commonly classified to be already precipitating.

Images from the CIP show that large liquid drops and ice crystals (many in excess of 500 µm radius) were frequently observed over the course of the cloud seeding operation. The average effective radius of drops and/or crystals from the CIP probe was 247 µm, well above size for precipitation.

The BoM's radar image (below) from the West Takone site at the commencement of seeding, at 11 AM (local time) on 5 June (with the approximate position of the seeding track added in red) demonstrates that precipitation is evident across the track prior to the commencement of the seeding. This precipitation is completely natural and could not be caused by cloud seeding, as this image is taken at the time the seeding commenced.



Next steps

Late on the afternoon of 6 June 2016, all hydro catchments were removed from the target list due to the heavy rainfall and strong inflows being received into hydro catchments, and as a result of concerns regarding the cloud seeding flight undertaken on 5 June.

Having undertaken an initial review of the cloud seeding program, Hydro Tasmania has identified areas of the program and the procedures that we follow that require more detailed review and potential improvements, including in relation to seeding when there is a risk of floods. Hydro Tasmania's cloud seeding program remains on hold and will not resume until a full internal review of the program has been completed, any appropriate improvements have been implemented, and extensive stakeholder engagement has been undertaken.

It is not expected that cloud seeding will be undertaken again this season.

An Analysis of the Cloud Seeding Event of 5 June 2016

Assoc. Prof. Steven Siems
Monash University
10 November2016

CONFIDENTIAL

Executive Summary

Hydro Tasmania undertook glaciogenic cloud seeding on Sunday 5 June 2016 for 94 minutes (10:57 – 12:31 AEST). The cloud/storm system that was seeded was already precipitating freely. From the aircraft's Cloud Imaging Probe (CIP) of the Cloud Aerosol and Precipitation Spectrometer (CAPS), there is ample evidence that rain-sized droplets and large ice particles were present along the seeding track (Support Document 1; FIG.2). These airborne observations are consistent with the Bureau of Meteorology's (BoM) ground-based radar observations at West Takone (Support Document 2), the Himawari-8 satellite imagery (Support Document 3) and the BoM's operational weather forecast (ACCESS, FIG.5).

I refer to the letter of instruction from Page Seager dated 1 November 2016. This report is aimed at addressing the following question posed in that letter:

Did Hydro Tasmania's cloud seeding flight on 5 June 2016 have any effect on the ensuing precipitation on that day and the following 48 hours?

Based on my analysis, it is my opinion that the cloud seeding undertaken had no measurable impact on precipitation on this day and the following 48 hours. The theoretical basis for glaciogenic cloud seeding was not valid for the cloud/storm system encountered. First and foremost, the cloud was already precipitating freely throughout the period of seeding, meaning that any seeding effort to initiate precipitation was completely redundant. Further, ample natural ice was evident immediately upon commencing the seeding flight and throughout the whole flight, again suggesting that cloud seeding would have no impact. There is no physical basis to support the premise that seeding under such conditions has a positive impact on the natural precipitation processes. This is discussed more fully in section 5.

1. Meteorological & Operational Summary

Given the severity of the flooding experienced on 6 June 2016, the Bureau of Meteorology issued Special Climate Statement 57 further detailing the extreme meteorology of the event. The meteorology was highly unusual given the progression of 'East Coast Lows' bringing warm, moist air southward from east coast of Australia onto Tasmania. The Mean Sea Level Pressure (MSLP) charts 5 June 2016 are shown in FIG.1.

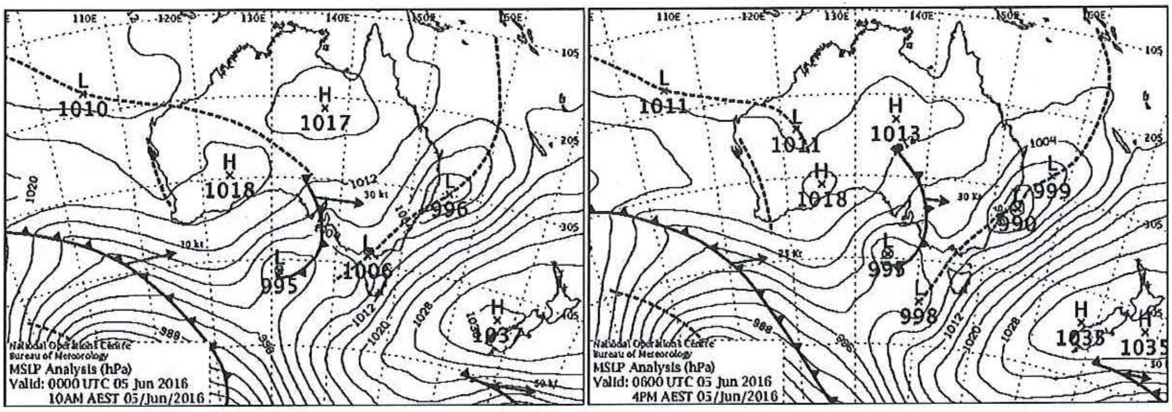


FIGURE 1. Mean Sea Level Pressure chart at 1000AEST (left) and 1600AEST (right) on 5 June 2016. Images are obtained from BoM.

On Sunday 5 June 2016, Hydro Tasmania undertook a glaciogenic cloud seeding flight for 94 minutes (10:57-12:31 AEST) with the intent of enhancing rainfall into the Hydro storages in the Upper Derwent catchment (including Lake Echo). Following operational procedures, the aircraft flew 30 minutes upwind of the target, based on local wind observations, which placed the aircraft over north central Tasmania. Seeding was undertaken at an altitude where the ambient temperature was between -8° and -10°C, which was recorded to be at ~17,000ft (~5200m) above sea level (ASL) by the pressure altimeter.

2. Objectives & Methodology

This report is aimed at addressing the following question:

Did Hydro Tasmania's cloud seeding flight on 5 June 2016 have any effect on the ensuing precipitation on that day and the following 48 hours?

The nature, structure and microphysical properties of the cloud/storm are first characterized employing the in-situ observations taken on-board the AusJet Cessna Conquest, satellite observations (Himawari-8), the BoM's radar observations from the West Takone site, the BoM's numerical weather forecast (ACCESS). Supplementary material includes numerical forward trajectories available on-line from the U.S. National Oceanic and Atmospheric Administration (NOAA).

3. In-situ observations

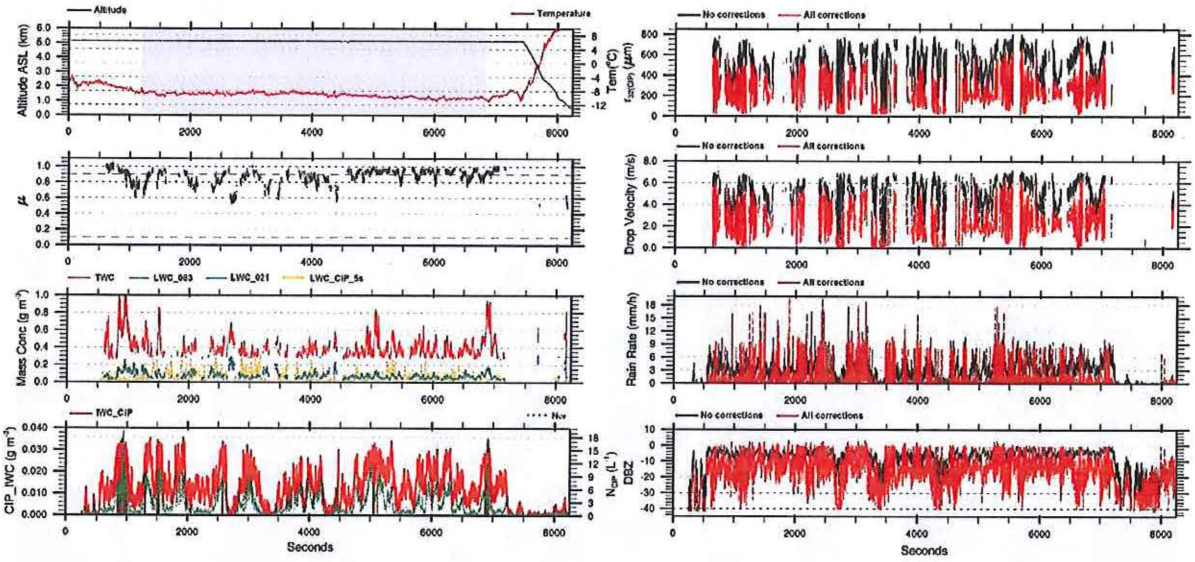


FIGURE 2. Time series of airborne observations (direct and processed) from the seeding flight on 5 June 2016. Blue shading in the top-left panel indicates the seeding period.

An overview of the airborne observations (direct and processed) from the aircraft data recording system (M300) is shown in FIG.2.

Instruments aboard the aircraft include a Droplet Measurement Technologies (DMT) Cloud Aerosol and Precipitation Spectrometer (CAPS) that incorporates:

- a hot-wire liquid water sensor,
- a single particle light scattering Cloud and Aerosol Spectrometer (CAS) that measures particles within the nominal size range of 0.6-50 µm in 30 size bins, and
- a Cloud Imaging Probe (CIP-25), an optical array probe that is used to record 2-D images of larger particles (50 µm-1.55 mm) in 62 size bins with a 25 µm resolution.

Bulk cloud water content is also measured using a Science Engineering Associates (SEA) WCM-2000 Multi-Element Water Content System, which has two independent cylindrical hot-wire elements (0.5 and 2 mm in diameter, conventionally named WCM-021 and WCM-083, respectively) for in-situ liquid water content, and a scooped 4-mm element for total water content (ice plus liquid).

Ambient and dew point temperatures are measured using a Meteolabor TP-3S (Meteolabor AG, Switzerland) that is mounted inside a reverse flow housing to avoid wetting of the sensing element by cloud hydrometeors.

The data presented were made at a temporal resolution of 1 Hz, which corresponds to a spatial scale of approximately 100 m based on the typical aircraft true air speed.

4 Analysis of cloud microphysics and precipitation

4.1 In-situ microphysics (CIP images and WCM-2000 bulk water content)

My analysis of the microphysics of these clouds depends heavily on both the cloud imaging probe (CIP) component of the DMT CAPS instrument and SEA WCM-2000 probe for bulk liquid and total water content. The CIP probe is usually 'zeroed' in clean air prior to entering clouds to prevent negative values of liquid water content being observed. As this procedure was not performed in this flight, a post-flight calibration was performed to correct the CIP observations using the SODA-2 software from the National Center for Atmospheric Research (NCAR). Both instruments consistently and readily observe the presence of ice throughout the seeding track, although there were small patches of ice-free cloud.

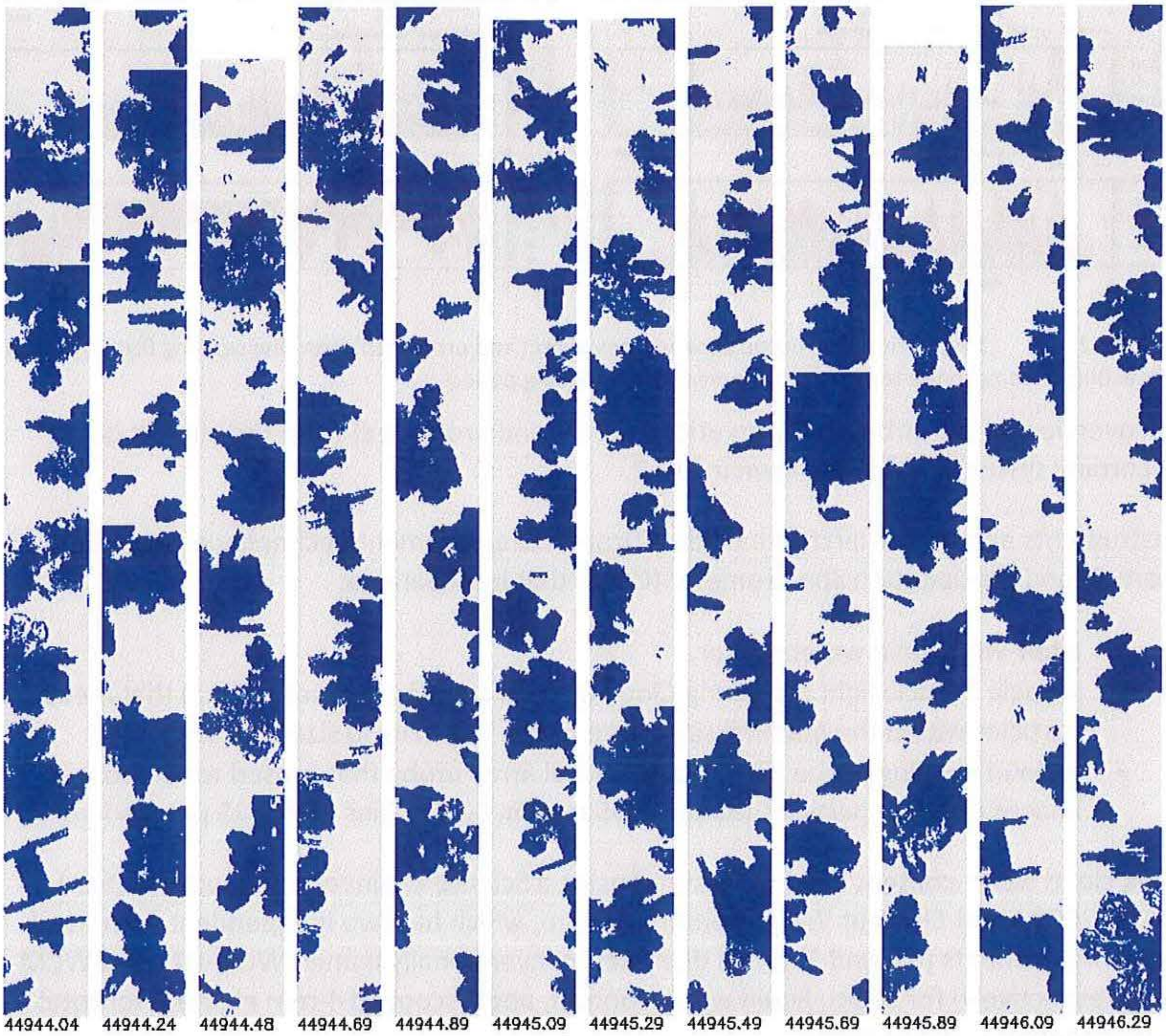


FIGURE 3. Example of the images recorded on the DMT Cloud Imaging Probe. This image reveals that at this point in time the cloud was heavily glaciated with large ice crystals. The blue is the shadow or shape of the ice crystals observed. Circles would suggest liquid drops instead of ice crystals, although it is possible to detect small frozen drops as circles.

Images from the cloud imaging probe are presented in supporting document 1. These images show that large liquid drops and ice crystals (many in excess of 500 µm radius) were frequently observed over the course of the cloud seeding (Figure 2). Drops and crystals above ~100 µm radius are commonly classified to be precipitating (including 'drizzle'). The mean effective radius of drops and/or crystals from the CIP probe was 247µm over the course of the seeding. This demonstrates that precipitation had freely developed well before any seeding occurred. (Note that cloud seeding is intended to work on small supercooled liquid water (SLW) droplets, generally of size 10 or less microns in radius.)

Analyzing the post-calibrated WCM measurements for the duration of the seeding finds that that the average total water content was 0.39g/kg. The average liquid water content (from the WCM-083 probe) was 0.09 g/kg. On these bulk figures, theoretically the average ice to total water content ratio during seeding was 0.86. That is, 86% of the total water content was ice. These figures suggest that **the sampled clouds were, on average, heavily glaciated**, which is consistent with the CIP observations.

It is important to note that the SEA WCM-2000 is a relatively new probe that has not been fully documented or appreciated in the scientific community like the DMT CAPS probe. It has been suggested that in mixed-phase conditions, the distinction between the liquid and ice may still be uncertain.

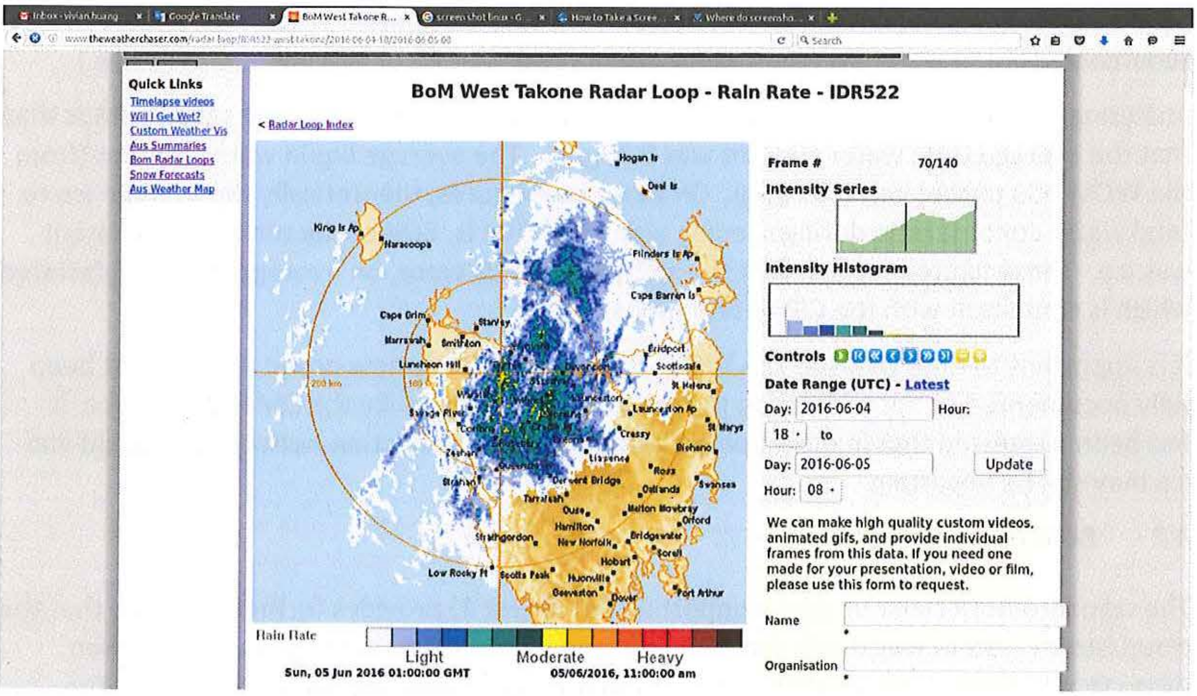
4.2 BoM radar observations

The standard BoM radar images (supporting document 2) provides further evidence that the cloud/storm system was freely precipitating long before cloud seeding was undertaken. (Note that a merged West Takone/Hobart radar product may also be used for this.) The radar images display the strength of the reflectivity produced from the precipitation (drops and crystals), thus giving a measure of the size/concentration of the precipitation field. These images are known as constant altitude plane position indicator (CAPPI) and are generally taken at an altitude of 2 km, rather than at the altitude of the seeding track (5.2 km).

At the time of the initial seeding the radar image reveals (Figure 4) that the heaviest precipitation was over the northwest portion of Tasmania, far removed from the seeding. Between Cressy and Liawenee, a band of light to moderate precipitation exists, which could not be a result of the seeding, because it is so far removed, and is upwind. Looking at the reflectivity two hours later (Figure 5), the storm is moving southward.

The evolution of the radar images in time suggests that seeding had no visible impact on the intensity of the precipitation. More intense precipitation cells are observed to advect along a heading of ~20°. The intensity of these cells is not observed to be enhanced as the cells move across the seeding track. This is NOT a scientifically rigorous argument, but at a basic level, demonstrates that there is precipitation already present AND seeding did not appear to increase the intensity of this existing precipitation.

As can be seen in the below images (and video that can be accessed at the site noted below), precipitation was evident across the seeding track throughout the period of seeding. The strength of the reflectivity can be employed to infer a precipitation rate, as shown in the diagram. Over the seeding track, the precipitation was light to very light. Over the west of the state, the precipitation reached a moderate intensity.



BoM West Takone Radar Loop - Rain Rate - IDR522

Frame # 70/140

Date Range (UTC) - Latest

Day: 2016-06-04 Hour: 18 to

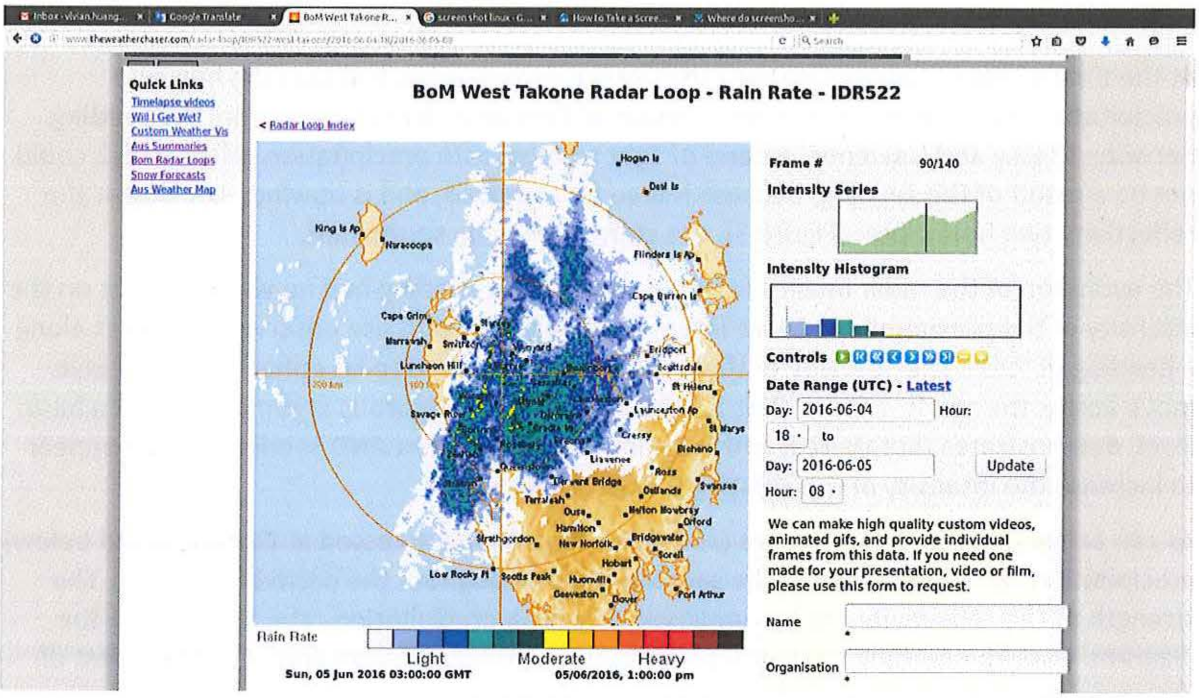
Day: 2016-06-05 Hour: 08

We can make high quality custom videos, animated gifs, and provide individual frames from this data. If you need one made for your presentation, video or film, please use this form to request.

Sun, 05 Jun 2016 01:00:00 GMT

05/06/2016, 11:00:00 am

FIGURE 4: The Bureau of Meteorology's radar image from the West Takone site at 11 AM (local time) in 5 June. Precipitation is evident across the track. This image highlights the spatial variability of precipitation. Note that the heavier precipitation to the south of Cressy could not be caused by cloud seeding, as this image is from the start of the seeding. This is completely natural precipitation.



BoM West Takone Radar Loop - Rain Rate - IDR522

Frame # 90/140

Date Range (UTC) - Latest

Day: 2016-06-04 Hour: 18 to

Day: 2016-06-05 Hour: 08

We can make high quality custom videos, animated gifs, and provide individual frames from this data. If you need one made for your presentation, video or film, please use this form to request.

Sun, 05 Jun 2016 03:00:00 GMT

05/06/2016, 1:00:00 pm

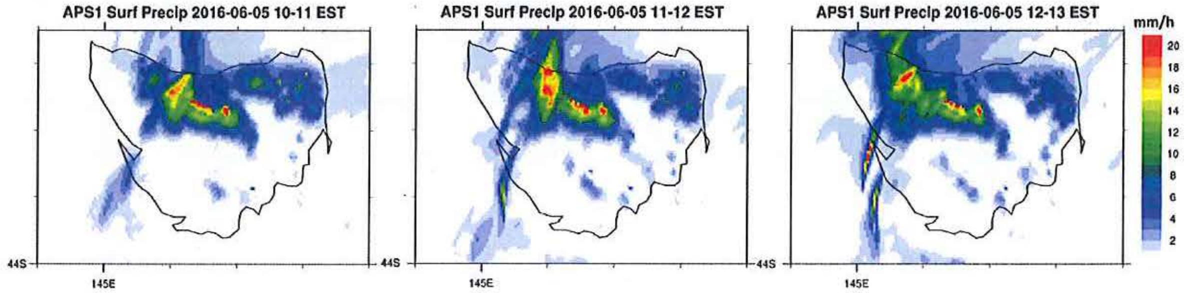
FIGURE 5. Same as figure 4, only for 1:00 pm local time.

Images may be found at:

http://www.theweatherchaser.com/radar-loop/IDR522-west-takone/2016-06-04-18/2016-06-05-08.

4.3 ACCESS forecast

We have also examined the hourly forecast precipitation from the BoM's ACCESS model (Figure 6.) In general, these forecasts are in 'good' agreement with the radar images. We note that quantitatively forecasting precipitation remains a great challenge to the meteorological community.


APS1 Surf Precip 2016-06-05 10-11 EST

APS1 Surf Precip 2016-06-05 11-12 EST

APS1 Surf Precip 2016-06-05 12-13 EST

FIGURE 6. Hourly accumulated precipitation forecast from the Bureau of Meteorology's ACCESS model for 11, 12 and 13 EST, respectively.

Further to the precipitation, we have examined a vertical profile (a 'thermodynamic' sounding) through the middle of the seeding track (Figure 7.) The profile suggests that the atmosphere was saturated or nearly saturated from the surface up to the tropopause at roughly 225 hPa. It is not clear where the simulated cloud-top is from this diagram, although it is likely to be in the neighborhood of 400 hPa, where the temperature is -30°C. The cloud top could be up at 225 hPa or ~-60°C, too. Either way, this is well below the temperature where cloud glaciogenic cloud seeding with silver iodide would be effective.

This profile also suggests that the cloud/storm system is convective. The deep updrafts and downdrafts within such a convective system will efficiently mix the cloud meaning that any supercooled liquid water observed is likely to be transient regardless of seeding. It will either be pushed up to colder temperatures (and freeze), pushed down to warmer temperatures, or come in contact with the natural ice already present.

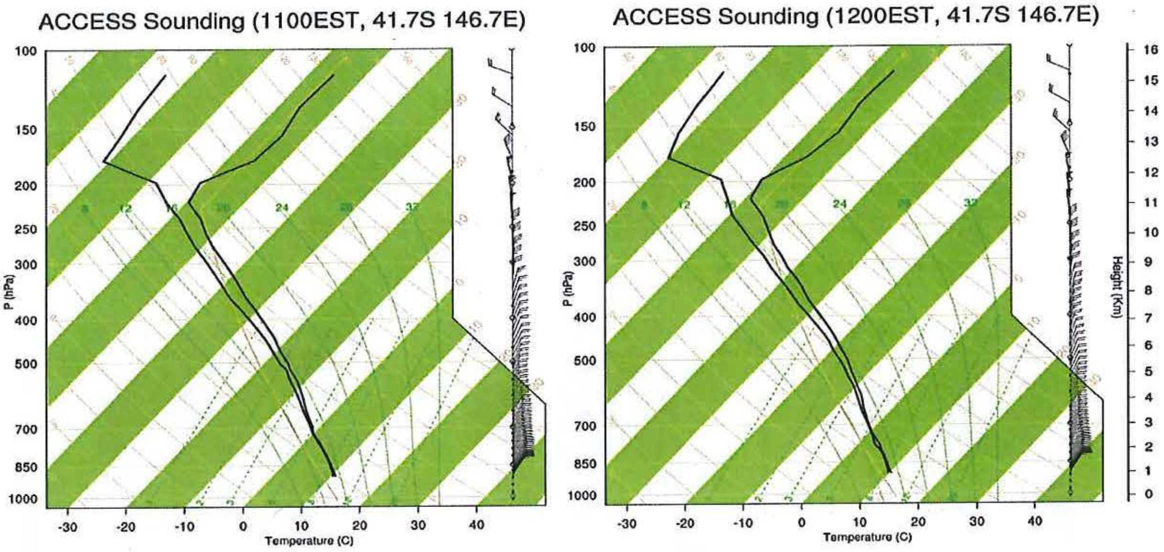


FIGURE 7. ACCESS sounding profiles taken at the mid-point of the virtual seeding track at 1100 and 1200AEST (seeding period), respectively.

4.4 Satellite imagery

The images (supporting document 3) are of the cloud top brightness temperature as observed by the Himawari-8 satellite. Throughout the day, the cloud tops are at temperatures below -40°C. This is colder than the temperatures necessary for homogeneous ice nucleation to occur (Figure 8.)

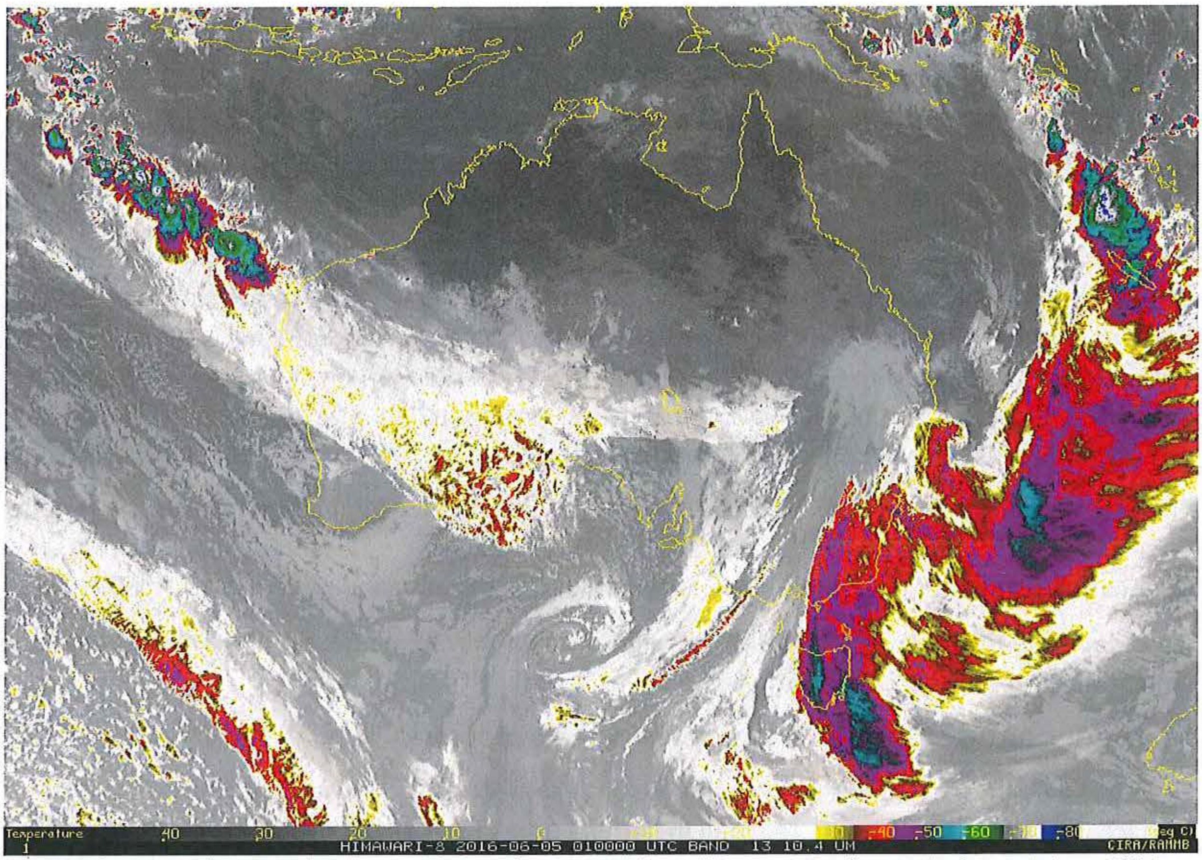


FIGURE 8. The cloud brightness temperature image from Himawari-8 taken at 11 AM on 5 June 2016 (EST). The images shows that the clouds over Tasmania were very deep with temperatures around -50°C.

In simple terms this suggests that plenty of ice will be present in these clouds. The tops will be completely glaciated – super cooled liquid water does not exist at such cold temperatures. When coupled with the ACCESS thermodynamic profile (FIG.7) in the main report, this suggests that ice should be present deep into the cloud. This is consistent with the CIP images. The image also suggests that deep convection was present through the cloud/storm system.

5 Discussion on the effectiveness of cloud seeding in active precipitation

As far as I am aware, there is no record of any attempt, in Tasmania or elsewhere, to undertake glaciogenic cloud seeding in the deep, convective, precipitating, mixed-phase clouds, as were encountered on 5 June 2016 (i.e. an 'East Coast low.') Certainly such clouds are not the typical westerly clouds that have historically been seeded in Tasmania (Ryan and King, 1997).

The theoretical development of precipitation in warm (i.e. no ice processes) clouds is well understood. Starting with small liquid droplets, these droplets will initially grow through condensation in a saturated environment. Once the droplets have grown to a size of roughly 20 microns (diameter), the bigger ones will begin to fall relatively to smaller droplets. Smaller droplets within the path of bigger droplets commonly become collected by the bigger droplets (collision and coalescence), which allows the bigger droplets to grow even more rapidly, fall more rapidly and collect even more smaller droplets. A positive chain reaction is set off that allows the big droplets to grow to sizes of at least 100 microns radius at which point we say that they are drizzling (a minor form of precipitation). Larger drops (250+ microns radius) are 'precipitating'.

If a cloud consists of small supercooled liquid water (SLW) droplets, the initial growth by condensation may be relatively slow. Clouds can persist in this state for long periods of time and may not even further develop to a stage of precipitation.

As commonly stated, glaciogenic cloud seeding is a process of introducing ice nuclei to SLW clouds. In a suitable seeding environment, these ice nuclei will convert (nucleate) the SLW droplets into ice crystals. The ice crystals are able to grow efficiently through condensation (often at the expense of the SLW) according to the Wegener-Bergeron-Findeisen process. Once the ice crystals are big enough, they will fall relative to the SLW droplets. Collision and coalescence will follow, similar to the warm cloud processes, and precipitation will follow.

This development going from cloud seeding to precipitation reaching the surface can readily take 30 minutes, as calculated by the CSIRO during the early cloud seeding experiments (Ryan and King, 1997), although there are many factors that can change this time estimate.

If a cloud is readily precipitating (either as liquid, ice or mixed phase), the collision and collection process is already underway.

Introducing further ice nuclei will not enhance this process.

Even if the cloud seeding were to nucleate some smaller SLW droplets and convert them into ice, they would still be quite small in comparison to the larger drops/ice crystals that are already present. These larger drops/crystals will continue to collect the smaller droplets/ice crystals, whether they have been nucleated or not.

It doesn't matter if short patches of ice-free conditions are encountered by the aircraft.

This East Coast Low storm is dynamic, and the updrafts and downdrafts are far too large. They will overwhelm any local patches of cloud that may have been susceptible to cloud seeding.

To employ a limited analogy, consider a field of dried grass. If you introduced a lit match to the field at the right location, in the right conditions, you could start a grass fire. Once the fire is fully developed, adding another match to the midst of it is of no consequence. Based on the clouds/storm system present on 5 June 2016, the seeding would be comparable to throwing a match or two into a fully developed bonfire. It was of no consequence.

In summary, the cloud/storm system of 5 June 2016 was not suitable for cloud seeding for a number of reasons, most notably because precipitation was already present. Furthermore, the cloud was heavily glaciated along the seeding track.

5.1 Historical context for the effective of cloud seeding over Tasmania

We commonly speak of cloud seeding 'enhancing' rainfall. For example, Morrison et al. (2009) made such an estimate on the effect of cloud seeding on the *monthly rainfall* over the period from 1960-2005 and found that a 5-13% average enhancement was observed, and that this enhancement was statistically significant in 9 out of 10 tests. The historical cloud seeding field experiments conducted by the CSIRO reported that the average precipitation enhancement was 30% for the first cloud seeding trial (Tasmania I) and 37% for the second trial (Tasmania II) (Ryan and King, 1997).

As discussed earlier, the cloud/storm system of 5 June 2014 was not similar to the systems seeded for Tasmania I and II, which means that these bulk enhancements are not valid or even necessarily provide a good estimate.

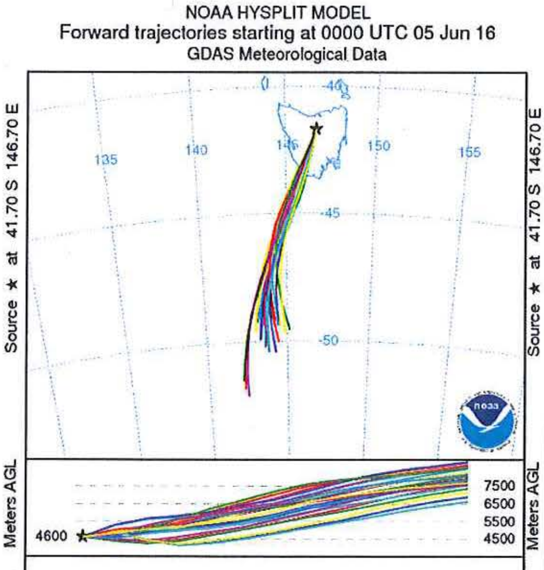
Note that it can be misleading to speak of an 'enhancement' to precipitation from cloud seeding in terms of percentages. If there is little natural precipitation present, then it is possible to get a 'large' enhancement. For example, if the natural precipitation was 1 mm per hour, and cloud seeding increased it to 2 mm per hour, then there was a 100% enhancement. If, however, the natural precipitation was 10 mm per hour, and cloud seeding increased it to 11 mm per hour, then there was only a 10% enhancement.

6 Trajectory analysis

The following forward trajectories explain why regardless of whether cloud seeding were effective shortly after the flight (which I have concluded it was not), it would not have had any further effect over Tasmania for the following 48 hours.

The analysis below suggests that any silver iodine that was not washed out in the storm would have been rapidly carried far away from Tasmania and would have no impact on any precipitation over Tasmania over the next 48 hours.

12-hour forward trajectories at various altitudes calculated by the HYbrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) Model (http://ready.arl.noaa.gov/HYSPLIT.php) using the Global Data Assimilation System (GDAS) data were produced (supporting document 4.) Longer duration back trajectories show the seeded air mass moving further south and east over the next 36 hours. It does not recirculate over Tasmania.



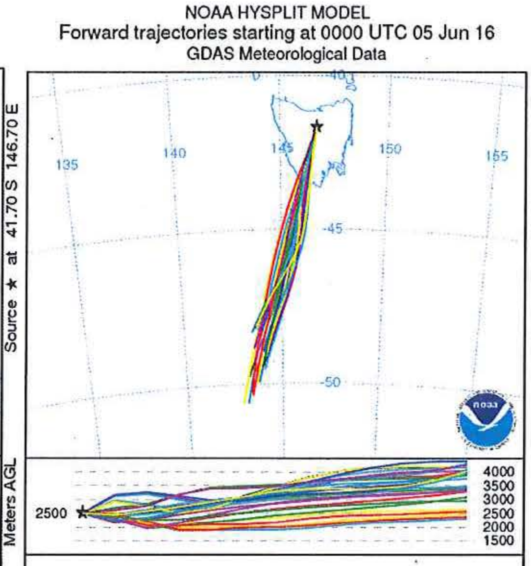


FIGURE 10. HY-SPLIT 12-hour forward trajectories starting at an elevation of 4600 m (left) and 2500 m (right).

6. Concluding Statement

I conclude that the cloud/storm system encountered was not suitable for glaciogenic cloud seeding. This is based on a comprehensive analysis of the available meteorological observations (radar, satellite, numerical forecasts and in-situ observations.) I do not believe that the seeding undertaken had any impact on the immediate precipitation, let alone the precipitation over the next 24 to 48 hours.

Steven J. Siems

Assoc. Prof. Steven Siems

Curriculum Vitae

STEVEN THOMAS SIEMS

June 2016

QUALIFICATIONS:

1987 - 1991:	PhD, Applied Mathematics, University of Washington. Dissertation: *Numerical simulations of cloud-top entrainment instability and related experiments*.
1985 - 1987:	MSc, Applied Mathematics, University of Washington.
1981 - 1985:	BSc, Applied Mathematics, University of Missouri-Rolla. Awarded *summa cum laude*. Minors in Computer Science and Physics.

PRESENT APPOINTMENT:

1994 - Present:	Monash University. Associate Professor, School of Earth, Atmosphere and Environment *and* School of Mathematical Sciences.

PREVIOUS APPOINTMENTS:

1993 - 1994:	U.S. National Science Foundation Overseas Fellowship, UMIST, Manchester, England.
1991 - 1993:	Postdoctoral Fellow, Advanced Studies Program, National Center for Atmospheric Research, Boulder, CO, USA.
1987 - 1991:	Graduate Research Assistant, University of Washington, WA, USA.
1988 (summer):	Graduate Fellow, Geophysical Fluid Dynamics program, Woods Hole Oceanographic Institute, USA.
1987 (summer):	Summer Graduate Intern, McDonnell Douglas Research Laboratories, St. Louis, MO, USA.
1985 - 1987:	Pre-doctoral Lecturer and Graduate Teaching Assistant, Mathematics Department, University of Washington, WA, USA.
1986 (summer):	Outstanding Summer Graduate Student, Sandia National Laboratories, Livermore, CA, USA.
1983 - 1985:	Student Teaching Assistant, Math and Statistics Department, University of Missouri-Rolla, USA.

RESEARCH ACTIVITIES:

Refereed Journal Publications:

2016	Wang, Z., D. Belusic, Y. Huang, S. T. Siems, M. J. Manton, 2016: Understanding orographic effects on surface observations at Macquarie Island. *J. Appl. Met. and Clim.*, **55**, 2377-2395, DOI: 10.1175/JAMC-D-15-0305.1.
2016	Murphy, M.J. Jr., S. T. Siems, M. J. Manton, 2016: Regional variation in the wet season of Northern Australia. *Mon. Wea. Rev.*, (on-line Sept. 2016).
2016	Huang, Y., S. T. Siems, M. J. Manton, D. Rosenfeld, R. Marchand, G. M. McFarquhar and A. Protat, 2016: What is the role of Sea Surface Temperature in Modulating Cloud and Precipitation Properties over the Southern Ocean? *J. Clim.*, **29**, 7453-7464, DOI: 10.1175/JCLI-D-15-0768.1

2016	Jovanovic, B., R. Smally, B. Timbal and S. Siems, 2016: Homogenised monthly upper-air temperature dataset for Australia. *Int. J. Climatology* (accepted June 2016).
2016	Chubb, T. H., M. J. Manton, S. T. Siems and A. D. Peace, 2016: Evaluation of the AWAP daily precipitation spatial analysis with an independent gauge network in the Snowy Mountains. *J. Southern Hemisphere Earth System Science*, **66**, 55-67.
2016	Chubb, T., Y. Huang, J. Jensen, T. Campos, S. Siems and M. Manton, 2016: Observations of high droplet number concentrations in Southern Ocean boundary layer clouds. Atmos. Chem. Phys., **16**, 971-987, doi:10.5194/acp-16-971-2016.
2016	Osburn, L., T.H. Chubb, S.T. Siems and M.J. Manton, 2016: Observations of Supercooled liquid water in wintertime alpine storms in South Eastern Australia. *Atmos. Res.*, **169**, 345-356, doi:10.1016/j.atmosres.2015.10.007.
2015	Chubb, T.H., M.J. Manton, S.T. Siems, A.D. Peace and S.P. Bilish, 2015: Estimation of wind-induced losses from a precipitation gauge network in the Australian Snowy Mountains. *J. Hydrometeor.,* **16**, 2619-2638, doi:10.1175/JHM-D-14-0216.1.
2015	Wang, Z., S.T. Siems, D. Belusic, M.J. Manton and Y. Huang, 2015: A Climatology of the Precipitation over the Southern Ocean as observed at Macquarie Island. *J. Applied Meteor. Clim.*, **54**, 2321-2337, doi:11.1175/JAMC-D-14-0211.1.
2015	Prata, A.T., S.T. Siems and M.J. Manton, 2015: Quantification of volcanic cloud top heights and thicknesses using A–train observations for the 2008 Chaitén eruption. *J. Geophys. Res*., **120**, 2928-2950, D18204, DOI:10.1002/2014JD022399.
2015	Huang, Y., A. Protat, S.T. Siems and M.J. Manton, 2015: A-Train observations of maritime midlatitude storm-track cloud systems: Comparing the Southern Ocean against the North Atlantic. *J. Clim.*, **28**, 1920-1939, DOI:10.1175/JCLI-D-14-00169.1.
2015	Huang, Y., C.N. Franklin, S.T. Siems, M.J. Manton, T. Chubb, A. Lock, S. Alexander and A. Klekociuk, 2015: Evaluation of boundary layer cloud forecasts over the Southern Ocean in a limited-area numerical weather prediction system using in-situ, space-borne and ground-based observations. *Quart. J. Royal Meteor. Soc.*, **141**, 2259-2276, DOI:10.1002/qj.2519.
2015	Hande, L.B., D.H. Lenschow, S.T. Siems and M.J. Manton, 2015: An evaluation of COSMIC radio occultation data in the lower atmosphere over the Southern Ocean. *Atmos. Meas. Tech.*, **8**, 97-107, DOI:10.5194/amt8-97-2015.
2014	Dai, J., M.J. Manton, S.T. Siems and E.E. Ebert, 2014: Estimation of daily winter precipitation over the Snowy Mountains of South Eastern Australia, 2014. *J. Hydrometeorology*, **15**, 909-920, DOI: 10.1175/JHM-D-13-081.1
2014	Huang, Y., S.T. Siems, M.J. Manton and G. Thompson, 2014: An Evaluation of the WRF Simulations of the Clouds over the Southern Ocean with A-Train Observations. *Monthly Weather Review,* **142***, 647-667,* DOI: 10.1175/MWR-D-13-00128.1
2013	Chubb, T.H., J.B. Jenson, S.T. Siems and M.J. Manton, 2013: In-situ observations of supercooled liquid clouds over the Southern Ocean during the HIAPER Pole-to-Pole Observations (HIPPO) campaigns. *Geophys. Res. Letters*, **40**, 5280–5285, doi:10.1002/grl.50986.

2013	Johnson, C.D., S.T. Siems, M.J. Manton and E.E. Ebert, 2013: An evaluation of the precipitation forecasts of the Poor Man's Ensemble for wintertime rainfall across the southern portion of Australia. *Austral. Meteor. and Ocean. J.*, **63**, 315-324.
2013	Morrison, A.E., S.T. Siems and M.J. Manton, 2013: On a natural environment for glaciogenic cloud seeding. *J. Appl. Meteor. and Climatol.*, **52**, 1097-1104, doi:10.1175/JAMC-D-12-0108.1.
2013	Caine, S., T. P. Lane, P.T. May, C. Jakob, S.T. Siems, M.J. Manton and J. Pinto, 2013: Statistical assessment of tropical convection-permitting model simulations using a cell-tracking algorithm. *Mon. Wea Rev.*, **141**, 557-581, DOI:10.1175/MWR-D-11-00274.1.
2013	Wilson, L., M.J. Manton and S.T. Siems, 2013: Relationship between rainfall and weather regimes in south-eastern Queensland, Australia. *Int. J. Climatology*, **33**, 979-991, DOI: 10.1002/joc.3484.
2012	Chubb, T., S. Caine, A. Morrison, S. Siems and M. Manton, 2012: Orographic influence on clouds and precipitation in the Brindabella Ranges. *Austral. Meteor. and Ocean. J.*, **62**, 305-321.
2012	Huang, Y., S.T. Siems, M.J. Manton, A. Protat, and J. Delanoë, 2012: A study on the low-altitude clouds over the Southern Ocean using the DARDAR-MASK. *J. Geophys. Res.*, **117**, D18204, doi:10.1029/2012JD017800.
2012	Hande, L.B., S.T. Siems, and M.J. Manton, 2012: Observed Trends in Wind Speed over the Southern Ocean. *Geophys. Res. Lett.*, **39**, L11802, doi:10.1029/2012GL051734.
2012	Hande, L.B., S.T. Siems, M.J. Manton, and D. Belusic, 2012: Observations of wind shear over the Southern Ocean. *J. Geophys. Res.*, **117**, D12206, doi:10.1029/2012JD017488.
2012	Huang. Y., S.T. Siems, M.J. Manton, L.B. Hande and J.M. Haynes, 2012: The structure of low-altitude clouds over the Southern Ocean as seen by CloudSat. *J. Climate*, **25**, 2535-2546, DOI: 10.1175/JCLI-D-11-00131.1.
2012	Tessendorf, S.A,, R.T. Bruintjes, C. Weeks, J.W. Wilson, C.A. Knight, R.D. Roberts, J.R. Peter, S. Collis, P.R. Buseck, E. Freney, M. Dixon, M. Pocernich, K. Ikeda, D. Axisa, E. Nelson, P.T. May, H. Richter, S. Piketh, R.P. Burger, L. Wilson, S.T. Siems, M. Manton, R.C. Stone, A. Pepler, D.R. Collins, V.N. Bringi, M. Thurai, L. Turner and D. McRae, 2012: The Queensland Cloud Seeding Research Program. *Bull. Amer. Meteor. Soc.*, **93**, 75-90, doi:10.1175/Bams-d-11-00060.1.
2011	Chubb, T.H., S.T. Siems and M.J. Manton, 2011: On the decline of wintertime precipitation in the Snowy Mountains of South-Eastern Australia. *J. Hydrometeorology,* **12**, 1483-1497, DOI: 10.1175/JHM-D-10-05021.1.
2011	Morrison, A.E., S.T. Siems and M.J. Manton, 2011: A three-year climatology of cloud-top phase over the Southern Ocean and North Pacific. *J. Clim.,* **24**, 2405-2418, DOI10.1175/2010JCLI3842.1.
2010	Jinsart, W., C. Sripraparkorn, S.T. Siems and P.J. Hurley, 2010: Application of The Air Pollution Model (TAPM) to the urban airshed of Bangkok, Thailand. *Int. J. Environment and Pollution*, **42**, 68-84, DOI: 10.1504/IJEP.2010.034227.
2010	Morrison, A.E., S.T. Siems, M.J. Manton, A. Nazarov, 2010: A Modelling Case Study of Mixed Phase Clouds over the Southern Ocean and

	Tasmania. *Monthly Wea. Rev.,* **138**, 839-862, DOI: 10.1175/2009MWR3011.1.
2010	Wapler, K., T.P. Lane, P.T. May, C. Jakob, M.J. Manton and S.T. Siems, 2010: Cloud system resolving model simulations of tropical cloud systems observed during the Tropical Warm Pool-International Cloud Experiment. *Monthly Wea. Rev.,* **138**, 55-73, DOI: 10.1175/2009MWR2993.1
2010	Peter, J.R., S.T. Siems, J.B. Jensen, J.L. Gras, Y. Ishizaka and J.M. Hacker, 2010: Airborne observations of the effect of a cold front on the aerosol particle size distribution and new particle formation. *Q. J. R. Met. Soc.,* **136**, 944–961. DOI:10.1002/qj.515.
2009	Gras, J.L., S.I. Jimi, S.T. Siems and P.B. Krummel, 2009: Postfrontal nanoparticle at Cape Grim: observations. *Environmental Chemistry*, **6**, 508-514, doi:10.1071/EN09075.
2009	Morrison, A.E., S.T. Siems, M.J. Manton and A. Nazarov, 2009: On the Analysis of a Cloud Seeding Data Set over Tasmania, *J. Appl. Meteor. and Clim.*, **48**, 1267-1280, doi: 10.1175/2008 JAMC2068.1.
2009	Caine, S., C. Jakob, S. Siems and P. May, 2009: Objective Classification of Precipitating Convective Regimes Using a Weather Radar in Darwin, Australia. *Monthly Wea. Rev.*, **137**, 1585-1600, DOI: 10.1175/2008MWR 2532.1.
2008	Jimi, S.I., S.T. Siems, J. McGregor, J.L. Gras and J. Katzfey, 2008: An investigation into the origin of aerosol nucleation events observed in the Southern Ocean boundary layer. *Australian Met. Mag.,* **57**, 85-93.
2007	Jimi, S.I., J.L. Gras, S.T. Siems and P.B. Krummel, 2007: A short climatology of nanoparticles at the Cape Grim Baseline Air Pollution Station, Tasmania. *Environmental Chemistry,* **4**, 301-309.
2006	Peter, J.R., S.T. Siems, J.B. Jensen, J.L. Gras, Y. Ishizaka and J.M. Hacker, 2006: Prediction and observation of cloud processing of the aerosol size distribution by a band of cumulus, *Q. J. R. Met. Soc.*, **132**, 845-863, doi: 10.125/qj.05.106.
2005	McGibbony, S., S.T. Siems, W.L. Physick and P. Hurley, 2005: The sensitivity of simulations of air pollution events at Cape Grim to the modelled meteorology, *Aus. Met. Mag*., **54**, 321-332.
2005	Cox, M.L., G.A. Sturrock, P.J. Fraser, S.T. Siems and P.B. Krummel, 2005: Identification of Regional Sources of Methyl Bromide and Methyl Iodide from AGAGE Observations at Cape Grim, Tasmania. *J. Atmos. Chem.*, **50**, 59-77.
2004	Cox, M.L., P.J. Fraser, G.A. Sturrock, S.T. Siems and L.W. Porter, 2004: Terrestrial sources and sinks of halomethanes near Cape Grim, Tasmania. *Atmos. Env.*, **38**, 3839-3852.
2003	Cox, M.L., S.T. Siems, P.J. Fraser, P. Hurley and G. Sturrock, 2003: TAPM modelling studies of AGAGE dichloromethane observations at Cape Grim, in *Baseline Atmospheric Program (Australia) 1999-2000*, edited by P.J. Fraser, N. Derek and N.W. Tindale, Bureau of Meteorology and CSIRO AR, Melbourne, Australia, 54-60.
2003	Jimi, S.I., J.L. Gras and S.T. Siems, 2003: Nano-particles at Cape Grim: a regional view using Southern Ocean Atmospheric Photochemistry Experiment (SOAPEX-2) as a case study. *Baseline Atmospheric Program (Australia) 1999-2000*, edited by P.J. Fraser, N. Derek and N.W. Tindale, Bureau of Meteorology and CSIRO AR, Melbourne, Australia, 25-30.

2003 Cox, M.L., G.A. Sturrock, P.J. Fraser, S.T. Siems, P.B. Krummel, and S. O'Doherty, 2003: Regional sources of methyl chloride, chloroform and dichloromethane identified from AGAGE observations at Cape Grim Tasmania, 1998-2000. *J. Atmos. Chem.,* **45***,* 79-99.

2000: Siems, S.T., G.D. Hess, K. Suhre, S. Businger, R.R. Draxler, 2000: A comparison of observed and simulated trajectories of the ACE-1 Lagrangian experiments. *Australian Met. Mag.,* **49**, *109-120.*

1999: Lenschow, D.H., P.B. Krummel and S.T. Siems, 1999: Measuring entrainment, divergence and vorticity on the mesoscale from aircraft, *J. Atmos. and Ocean. Tech.,* **16**, 1383-1399.

1999: Businger, S., J. Katzfey, R. Johnson, S. Siems, and Q. Wang, 1999: Smart tetroons for Lagrangian air parcel tracking during ACE-1. *J. Geophys. Res.*, **104**, 11,709-11,722.

1999: Wang, Q., K. Suhre, P.B. Krummel, S.T. Siems, L. Pan, T.S. Bates, J.E. Johnson, D.H. Lenschow, B.J. Huebert, G.L. Kok, R.D. Schillawski, A.S.H. Prevot, S. Businger, 1999: Characteristics of the marine boundary layers observed during Lagrangian measurements. Part I: general conditions and mean characteristics. *J. Geophys. Res.,* **104**, 21751-21766.

1998: Boers, R., P.B. Krummel, S.T. Siems, G.D. Hess, 1998: Thermodynamic structure and entrainment of stratocumulus over the Southern Ocean. *J. Geophys. Res.,* **103**, 16,637-16,650.

1998: Russell, L.M., D.H. Lenschow, K.K. Laurson, P.K. Krummel, S.T. Siems, A.R. Bandy, D.C. Thorton, T.S. Bates, 1998: Bi-directional mixing in an ACE-1 marine boundary layer overlain by a second turbulent layer. *J. Geophys. Res.,* **103**. 16,411-16,432.

1998: Whittlestone, S., J.L. Gras, S.T. Siems, 1998: Surface air-mass origins during ACE-1. *J. Geophys. Res.,* **103**, 16,341-16,350.

1995: Bretherton, C.S., P.H. Austin and S.T. Siems, 1995: Cloudiness and marine boundary layer dynamics in the ASTEX lagrangian experiments. Part II: cloudiness, drizzle, surface fluxes and entrainment. *J. Atmos. Sci.,* **52**, 2724-2735.

1995: Austin, P.H., S.T. Siems and Y. Wang, 1995: Constraints on droplet growth in radiatively cooled stratocumulus clouds. *J. Geophys. Res.,* **100**, 14231-14243.

1994: Paluch, I.R., D.H. Lenschow, S.T. Siems, S. McKeen, G.L. Kok and R.D. Schillawski, 1994: Evolution of the subtropical marine boundary layer. Part I: comparison of soundings over the eastern Pacific from FIRE and HaRP. *J. Atmos. Sci.,* **51**, 1465-1479.

1993: Siems, S.T., D.H. Lenschow and C.S. Bretherton, 1993: A numerical investigation of the interaction between stratocumulus and the air overlying it. *J. Atmos. Sci.,* **50**, 3663-3676.

1992: Siems, S.T. and C.S. Bretherton, 1992: A numerical investigation of cloud-top entrainment instability and related experiments. *Quart, J. Roy. Meteor. Soc.,* **118**, 787-818.

1990: Siems, S.T., C.S. Bretherton, M.B. Baker, S.S. Shy, and R.E. Breidenthal, 1990: Buoyancy reversal and cloud-top entrainment instability. *Quart. J. Roy. Meteor. Soc.*, **116**, 705-739.

Contributions to Books

2013: Cloud Seeding. Encyclopedia of Natural Hazards, Bobrowsky, P.T. (ed.), 2013, XLI, 1135 Springer ISBN 978-90-481-8699-0. *P 92.*

Non-Refereed Publications:

2014: Marchand, R., R. Wood, C. Bretherton, G. McFarqhuar, A. Protat, P. Quinn, S. Siems, C. Jakob, S. Alexander, B. Weller: *The Southern Ocean Clouds, Radiation, Aerosol Transport Experimental Study: White paper.* University of Washington.

2011: Siems, S., M. Manton, S. Caine, T. Chubb and A. Morrison: Exploring the potential for glaciogenic cloud seeding over Victoria: Analysis of a MODIS-based climatology and low-resolution WRF simulations. Dept. of Sustainability and Environment Research Report.

2002: Valianatos, O.D., P. Billings, K. Tolhurst, S. Siems, N. Tapper: *Fire Management: Modelling transport, dispersion and secondary pollutant formation of emissions from burning vegetation.* Dept. of Natural Resources and Environment Research Report.

Lead Investigator in Research Grants & Contracts:

2015 – 2017: Australian Antarctic Division (AAD4340) – Boundary Layer Processes over the Southern Ocean: Winds, Turbulence and Clouds. Siems, Alexander, Belusic, de Boer, Hamilton, Manton.......... Logistical Support

2015 – 2017: Australian Research Council (discovery grant DP150102894) – The Southern Ocean boundary layer: winds, turbulence sea spray and clouds. Siems, Belusic, Manton, Sullivan, Keywood and Schulz $404,000

2013 – 2016: Australian Research Council (linkage grant LP130100679) – Improving the physical understanding, numerical simulation and forecasts of severe storms and precipitation events over major Australian cities. Siems, Stone, Ramsay, Manton, Protat, Mushtaq and Siskas ..$590,000

2012 – 2016: Australian Research Council (linkage grant LP120100115) – Precipitation in wintertime storms across Southeast Australia, Tasmania and the Southern Ocean. Siems, Manton, Ebert, Franklin, Protat, Kenyon, Peace and Carson $1,340,000

2011 – 2012: Research contract with Snowy Hydro Ltd. on evaluating precipitation forecasts over the Snowy Mountains. Siems, Manton, Chubb and Dai. $48,000

2010 – 2011: Research contract with Victorian Dept of Sustainability and Environment on the potential for orographic precipitation over the Victorian Alps. Siems, Manton, Morrison, Caine, Chubb $160,000

2010: Research contract with ActewAGL on orographic precipitation over the Brindella Catchment: Stage III. Siems, Manton, Morrison, Caine and Chubb..$220,000

2010: Research contract with ActewAGL on orographic precipitation over the Brindella Catchment: Stage II. Siems, Manton, Morrison, Caine and Chubb..$89,000

2009: Research contract with ActewAGL on orographic precipitation over the Brindella Catchment: Stage I. Siems, Manton, Morrison, Caine and Chubb..$25,000

2007 – 2009: Research contract with Snowy Hydro Ltd. on orographic precipitaton and cloud seeding. Siems, Manton. $250,000

2005 – 2008: Australian Research Council (linkage grant LP0562358) - *Precipitation Events over Tasmania and their Response to Weather Modification*. Siems, Reeder, Wardle, Clark, Stolp, Navaroz. $270,000

2005 – 2007: U.S. Department of Energy - *Numerical simulations of the response of deep convection to aerosols produced by regional wild fires over Northern Australia.* Siems ....$80,000(USD)

2001: US Office of Naval Research - *An inter-comparison during ACE-Asia*. S.T. Siems, J.M. Hacker and J.B. Jensen: ....$9,600(USD)

1999 – 2001: Australian Research Council (large grant A39927012) - *Aerosols evolution and frontal passages and clouds: ACE-Asia.* Siems, Jensen, Hacker and Huebert $224,000

Supporting Investigator in Research Grants & Contracts:

2016: US DOE Atmospheric Radiation Measurement program - Measurements of Aerosols, Radiation and CloUds over the Southern Oceans (MARCUS). (CI Greg McFarquhar)

2016: Australian Maritime National Facility (R/V Investigator) - Clouds, aerosols, precipitation, radiation and atmospheric composition over the Southern Ocean (CAPRICORN) (CI Alain Protat)....... Logistical Support

2015 – 2017: Australian Antarctic Division (AAS4308) – The Structure of Southern Ocean Clouds. Hamilton, Alexander, Belusic, Carpentier, Siems .... Logistical Support

2015 – 2017: Australian Antarctic Division (AAD4292) – The Antarctic Clouds and Radiation Experiment (ACRE). Alexander, Klekociuk, Lachlan-Cope, Reid, Franklin, Keywood, Protat, Snels, Jakob, Siems, Hamilton, McDonald, Marchand, Jumulet .... Logistical Support

2013: Australian Research Council (LEIF grant LE130100136) - Mobile weather radar system for advanced environmental monitoring and modeling. Walker, Deletic, Beringer, Siems, Sherwood, McCabe, Western, Moran, Gray, Lambert, Martin. $340,000

2008: Research contract with Queensland Climate Change Centre of Excellence – *Queensland Cloud Seeding Research Project*. Manton, Siems $110,000

2007 – 2009: Australian Research Council (discovery grant DP0770381) – *Tropical Convection and its Contribution to Climate Variability*. Lane, Manton, Siems, May, Jakob $270,000

2003 – 2005: Australian Research Council (DP0344744) - *Fire Scar Impacts on Surface Heat and Moisture Fluxes in Australia's Tropical Savannas and Feedbacks to Local and Regional Climate.* Tapper, Beringer, Siems, Hutley and Lynch..$208,000

Research Field Projects:

2008 (Jan)	Queensland Cloud Seeding Research Program
2006 - present	Field work with Hydro Tasmania cloud-seeding grant
2006 (Jan)	Participant in TWP-ICE Experiment
2001 (April):	Principal Scientist in ACE-Asia Experiment
2000 (Feb):	Principal Scientist in Divergence Measurement Experiment
1998 - 2001:	Scientific Steering Committee for ACE-Asia
1996 (Nov):	Mission Scientist in Southern Alps Experiment (SALPEX)
1995 (Nov):	Principal Scientist in Aerosol Characterization Experiment (ACE-1)
1995 (Jan):	Participated in Southern Ocean Cloud Experiment (SOCEX-II)

1993 (Jul): Participated in Southern Ocean Cloud Experiment (SOCEX-I)
1993 (March): Mission Scientist in Central Equatorial Pacific Experiment (CEPEX)
1992 (June): Participated in Atlantic Stratocumulus Transition Experiment (ASTEX)

Contributions to Research Proposals:

2014: Southern Ocean Clouds, Radiation and Aerosol Transport Experimental Studies (SOCRATES) white paper
2006: CERF proposal
2005: ARC Centre of Excellence proposal
2004: Centre of Excellence for Risks and Opportunities for Climate Change
2000: Bushfire Cooperative Research Centre
1999: Monash University Fire Research Centre

Postgraduate & Honours Supervision:

active: Ms. Vidhi Bharti (PhD)
active: Ms. Fahimeh Sarmadi (PhD)
active: Ms. Belinda Roux (PhD)
active: Mr. Francisco Lang Tasso (PhD)
active: Ms. Eunmi Ahn (PhD)
active: Mr. Andrew Prata (PhD)
2016: Mr. Cameron Lewis (BSc Hon)
2016: Dr. Zhan Wang (PhD)
2016: Dr. Michael Murphy (PhD)
2015: Dr. Luke Osburn (PhD)
2014: Mrs. Branislava Jovanovic (MSc)
2013: Dr. Vivian Huang (PhD)

Winner of the Australian Meteorology and Oceanographic Society (AMOS) award for best PhD thesis. (The "Uwe Radok" award.)

2013: Dr. Luke Hande (PhD)
2013: Dr. Louise Wilson (PhD)
2012: Mr. Andrew Prata (BSc Hon)
2012: Ms. Megan Cash (BSc Hon)
2011: Mr. Christopher Johnson (BSc Hon)
2011: Dr. Thomas Chubb (PhD)
2009: Dr. Anthony Morrison (PhD)
2009: Dr. Simon Caine (PhD)
2008: Mr. Tom Wright (BSc Hon)
2008: Ms. Lan Oahn Nguyen (MSc)
2008: Dr. Valerio Bisignanesi (PhD)
2008: Dr. Mark Williams (PhD)
2007: Ms. Marie-Louise Tobin (BSc Hon)
2005: Ms. Clara Draper (MSc)
2006: Mr. Seb Henbest (MSc)
2006: Dr. Justin Peter (PhD)
2005: Dr. Salah Jimi (PhD)
2003: Ms. Jenny Farlow (BSc Hon)
2003: Ms. Sarah Arnup (BSc Hon)
2002: Mr. Steven McGibbony (BSc Hon)
2002: Dr. Michelle L. Cox (PhD)
1999: Ms. Karin C. Xuereb (MSc)
1999: Mr. Paul B. Krummel (MSc)

1996: Mr. Neil Plummer (MSc)
1995: Ms. Thuy Quach (BSc Hon)

TEACHING ACTIVITIES:

Units Lectured:

2015 - 2016:	ENG2091	Advanced Engineering Mathematics A
2009 - 2016:	MTH2010	Multivariable Calculus
2007 - 2016:	ATM3040	Dynamical and Physical Meteorology
2012:	ATM3050	Dynamical Meteorology
2007 - 2011:	M4451	Boundary Layer Meteorology (Honours)
2009 - 2010:	ATM1030	The Science of Weather
2005 - 2008:	ENG1091	Mathematics for Engineering
2001 - 2006:	ATM3010	Weather Phenomena
1999 - 2006:	M5551	Clouds & Aerosols (Honours)
2005:	MTH3360	Fluid Dynamics
2004:	MTH1030	Techniques for Modelling
2001 - 2004:	SCI2010	How Science Works
1999 - 2004:	ATM1010	The Dynamic Atmosphere
2003:	MTH1020	Analysis of Change
2003:	MAT1812	Mathematics II-D
2002:	MAT2901	Multivariable Calculus for Engineers
2002:	MAT2912	Mathematical Methods with Applications II
1999 - 2001:	MAT2911	Mathematical Methods with Applications I
2000:	ATM3162	Dynamical Meteorology
1999 - 2000:	SCI1010	How Science Works
1997 - 2000:	MAT3122	Dynamical Meteorology
1994 - 1999:	MAT2102	Introduction to Fluid Dynamics
1995 - 1998:	MAT2930	Numerical Methods for Engineers
1997:	MAT2941	Civil Engineering Mathematics
1997:	MAT1050	Mathematical Methods I
1995 - 1996:	A4101	Time Series and Data Analysis (Honours)
1995 - 1996:	MAA3111	Atmospheric Science

Other Lecturing:

1994 - 2004: Bureau of Meteorology Training Centre
2002 - 2006: Monash Winter School in Meteorology

Units Developed:

2007:	M4511	Boundary Layer Meteorology
2005:	ENG1091	Mathematics for Engineering
2001:	ATM3011	Weather Phenomena
1999:	M5551	Clouds & Aerosols
1999:	MAT2911	Mathematical Methods with Applications I
1997:	MAT2941	Civil Engineering Mathematics
1996:	MAA2042	Introduction to Fluid Dynamics (re-developed)

Undergraduate Mentoring:

1996 - 2008: Science Scholar Program

1996 - 2001: Deans Honour List Program

Workshops Attended:

2008: Serving on an Interview Panel
1998: Centre for Higher Ed. Development workshop on Flexible Learning
1995: Professional Development Centre workshop on Lecturing

ADMINISTRATIVE ACTIVITIES:

Offices Held:

2015 - present: Deputy Head, Earth, Atmosphere & Environment
2014: Convenor of Research Committee, Earth, Atmosphere & Environment
2013: Director of Research, Mathematics
2010: Coordinator, Undergraduate Atmospheric Science Program
2005 - 2009: Coordinator for BSc Adv and Science Scholars courses
2004 - 2006: Deputy Director, Centre for Dynamical Meteorology and Oceanography
2004 - 2012: Deputy Director of Undergraduate Studies, Mathematics
2003: Deputy Coordinator, Engineering Mathematics
2001 - 2003: Director, Centre for Dynamical Meteorology and Oceanography
2000: Deputy First Year Coordinator
1999 - 2001: Coordinator, Engineering Mathematics
1997 - 2006: Coordinator, Undergraduate Atmospheric Science Program
1996 - 1999: Deputy Director, Engineering Mathematics
1997 - 1998: Librarian, Department of Mathematics
1996: Acting Third Year Coordinator, Applied Mathematics
1996: Acting Director, Centre for Dynamical Meteorology and Oceanography
1996: Acting Education Program Leader, Cooperative Research Centre for Southern Hemisphere Meteorology

Committee Membership:

2013 - 2014: Faculty of Science Research Committee
2011 - 2013: Faculty of Science Promotions Committee (level D)
2010 - 2011: Talented Students Committee, Faculty of Science
2005 - 2009: School Representative to Engineering Faculty Board
2002 - 2007: Science Representative to Arts Faculty Board
2001 - 2004: Faculty of Science Promotions Committee (level B and C)
2001 - 2002: School Representative to Engineering Faculty Board
2000: Hargrave Library Committee
1996 - 2004: Environmental Science Advisory Committee
1996 - 1998: Hargrave Library Committee

Contributions to Academic Proposals:

2011: unit proposal – MON1001: Climate Change: An Interdisciplinary Challenge
2010: unit proposal – MTH2015: Multivariable Calculus Advanced
2007: unit proposal – ATM3040: Physical and Dynamical Meteorology
2007: unit proposal – ECE3093
2005: unit proposal – ENG2091: Advanced Engineering Mathematics A
2005: unit proposal – ENG2092: Advanced Engineering Mathematics B
2004: unit proposal – ENG1090: Foundation Mathematics

2004: unit proposal – ENG1091: Mathematics for Engineering
2000: unit proposal – ATM3011: Weather Phenomena
1999: unit proposal – ATM2022: Large Scale Weather & Climate
1998: unit proposal – ATM1010: The Dynamic Atmosphere
1998: degree proposal – B. Env. Sci.
1997: course proposal – ATM4000: Atmospheric Science Honours
1997: prize proposal – Academic prize for Atmospheric Science
1997: course proposal – ENV4000: B. Sc. (Honours) (Environmental)
1996: discipline proposal - Atmospheric Science undergraduate discipline (Proposal included submissions for two new units; ATM2121: Introduction to Atmospheric Sciences and ATM3121: Air Pollution Meteorology and Modelling)
1996: unit proposal - ENV3002: Environmental Monitoring

ADDITIONAL PROFESSIONAL ACTIVITIES:

Professional Associations**:**

2007 – present: Advisory Committee to Bureau of Meteorology Training Centre (Chair)
2007 – 2009: Queensland Cloud Seeding Research Program – Science Advisory Group
2006: reviewer of to 4th Intergovernmental Panel on Climate Change (ICCP) Science program
2004 – 2012: elected member of the International Commission on Clouds and Precipitation (ICCP) of the International Association of Meteorology and Atmospheric Sciences (IAMAS)
2013: European Geophysical Union
2013 – present: American Geophysical Union
1989 – present: American Meteorological Society
1993 – present: Royal Meteorological Society
1994 – present: Australian Meteorological and Oceanographic Society (AMOS)
2008 – 2012: AMOS Education Committee
2003 – 2004: AMOS Education Committee, chair

Conference Coordination:

2011: Member of the local planning committee for the IUGG conference
1997: Member of the local planning committee for IAMAS/IAPSO (joint assemblies of the Int. Assoc. of Meteorology and Atmospheric Sciences & Int. Assoc. for Physical Sciences of the Oceans)

Presentations on Behalf of Monash:

2002 – 2010: Presenter of Monash Award to secondary schools
2004 – 2008: Science Day representative at secondary schools

TERM OF REFERENCE 4: FORECASTING, ALERTS AND WARNINGS

The use and efficiency of forecasting, community alerts, warnings and public information by authorities in responding to flood events.

1 A SINGLE SOURCE OF PUBLIC FLOOD WARNINGS AND ALERTS

(a) During a potential flood emergency it is important that there is a single source of information. Mixed messages can lead to confusion, unnecessary damage to property and even lives being lost. The Bureau of Meteorology (BoM) provides a flood warning service for Tasmanian rivers. The Bureau delivers this service through its Flood Warning Centre and Regional Forecasting Centre based in Hobart.

(b) The warnings BoM provide are used by the Police, State Emergency Service (SES) and local authorities to plan their emergency responses.

(c) Hydro Tasmania does not provide flood warnings to the public nor does it provide predictions about the level of flooding as it could lead to mixed messages or confusion about what the situation is.

(d) Information on the flood warning services provided by BoM is available at:

http://www.bom.gov.au/water/floods/floodWarningServices.shtml

(e) The Tasmanian flood warnings are available at:

http://www.bom.gov.au/tas/warnings/index.shtml

2 HYDRO TASMANIA COLLECTS A RANGE OF WATER MONITORING DATA

2.1 Water Monitoring Data

(a) The water level, flow and rainfall monitoring sites operated by Hydro Tasmania are for the purpose of operating a hydro-generation system and in accordance with its operational requirements.

(b) Hydro Tasmania operates a network of automatic rain gauges, river level/flow sites and lake level probes which cover a wide geographic area associated with hydro generation activities.

(c) Typically Hydro Tasmania collects rainfall, level and flow data every half hour from its monitoring stations.

2.2 Hydro Tasmania's network

(a) There are a range of water monitoring sites throughout Tasmania, each of which have an identified owner. These owners include Hydro Tasmania, TasWater, Tasmanian Irrigation, BoM and Department of Primary Industry, Parks, Water and Environment (DPIPWE).

(b) Hydro Tasmania's hydrometric network comprises:

  (i) 48 pluviographs (rain gauges)

  (ii) 63 river (includes canals and flumes) level and flow sites

  (iii) 47 lake (or pond) levels

(c) The owner of each site is responsible for all aspects of the operation of the site including periodic downloading of the data. Once the data is available in the site owner's database it is transferred to other data users who may require it.

(d) Historically multiple data users were able to obtain information directly from each site but this led to difficulty identifying problems when a site failed. For example, it was often not clear which of the multiple users' equipment had failed causing a lack of access to the data for all users. The current system resolved this issue.

2.3 Data acquisition methods and rates

(a) Hydro Tasmania's network typically consists of remote solar powered sites, with data recorded on site by a data logger. Lakes and rivers record a value on the logger every 15 minutes and rain gauges record totals every 5 minutes.

(b) The data logger transmits a data file every 30 minutes via Internet Protocol (IP) communications (the internet) using 3G or satellite connections to a File Transfer Protocol (FTP) site. These devices can be subject to the same poor signal strength, high traffic load and bad weather issues as mobile phones.

Data files are re-transmitted by the logger if it detects that poor communications has prevented successful data transmission.

(c) Approximately every 30 minutes any new files arriving at the FTP site are processed and archived to the Hydro Tasmania database. Under normal operations data is up to 45-60 minutes old when it arrives on the Hydro Tasmania database.

(d) There are a number of hydrometric sites which use the more robust and high frequency SCADA network for transmitting data to Hydro Tasmania's hydrometric database. The SCADA network is Hydro Tasmania's highly reliable power station control system which connects Hydro Tasmania's major infrastructure by a high speed (non-public) network. Sites connected to this network are generally limited to those sites in close proximity to major infrastructure (e.g. power stations and intakes). Data is then transmitted from the SCADA system to Hydro Tasmania's hydrometric database every 30 minutes. The number of sites connected using this method is:

(i) 26 lake and pond levels

(ii) 4 river levels (and flow)

(e) Three SCADA river level sites mentioned above (Forth River below Paloona Power Station, Forth River above Lemonthyme Power Station and Derwent River below Meadowbank Power Station) also send data to Hydro Tasmania via an IP communications (internet) connection. This provides communications redundancy at these three sites if the SCADA at the nearby power station is unavailable.

(f) Equipment redundancy is uncommon in our hydrometric network.

2.4 Conversion of river level to river flow data

(a) It should be noted that none of Hydro Tasmania's river sites measure flow directly. Rather, river level is measured and converted to a flow. This is consistent with industry practice and equipment.

(b) To calculate river flow a relationship between river height and river flow is established over time by taking physical measurements of the flow over a range of heights. These spot flow measurements are called gaugings.

(c) A height to flow graph ('rating curve') is established by fitting a line of best fit through these gauging points.

(d) The river site will usually have a number of rating curves over its history as the relationship between height and flow changes when the river cross-section changes. Changes to the river cross-section normally occur during a major flood as material is either deposited or eroded at the site.

(e) It is rare (unlikely) that a gauging will have been obtained at or near the highest recorded river level. River flows above the highest recorded gauging are an estimate using both practitioner judgement and industry adopted methods for rating curve extension.

3 HYDRO TASMANIA'S DATA IS USED FOR A RANGE OF PURPOSES

3.1 Data is used to enable Hydro Tasmania's operations

(a) As noted above, the primary purpose of the water level, flow and rainfall monitoring sites operated by Hydro Tasmania is to assist Hydro Tasmania in operating a hydro-generation system and in accordance with its operational requirements.

(b) Some of the data that Hydro Tasmania collects is used in its internal water prediction models. These water flow models were developed for operational and asset management purposes. The outputs from these models are not provided to external agencies as they were specifically designed for Hydro Tasmania's internal purposes.

3.2 Some data is published on Hydro Tasmania's website

(a) Data is regularly published to Hydro Tasmania's publicly accessible web site. Many of the lake levels, rainfall and river flows are published here: http://www.hydro.com.au/water/water-levels-and-flows-map

(b) Data is published via static lake, river and rainfall plots (as PDFs). The frequencies at which these are created and published are:

(c) Lake levels: every 3 hours. Combining this with the normal data acquisition delays this can mean that the published data is up to 4 hours old.

(d) River levels, river flows and rainfall: every hour. Combining this with the normal data acquisition delays this can mean that the published data is approximately 2 hours old.

3.3 Some data is provided to BoM

(a) A selection of river level, river flow and rainfall data is regularly automatically exported to BoM via text file to an FTP site.

(b) The data transferred to BoM comprises:

  (i) 32 river levels

  (ii) 30 river flows

  (iii) 9 lake levels

  (iv) 26 rainfall sites

(c) The latest available data is transferred to an FTP site hosted by BoM every 30 minutes. Combining this with the normal data acquisition delays means that under normal operations the data can be up to 1 – 1.5 hours old at time of export. The time for BoM to ingest this data into their hydrometric database is not known by Hydro Tasmania.

(d) This data is then accessible by the general public via the BoM flood warning services.

4 HYDRO TASMANIA'S INTERACTIONS WITH BOM

(a) Hydro Tasmania assists BoM by providing access to flow, water level and rainfall data which BoM then uses as part of its flood prediction models. Hydro Tasmania has been providing this information for over 10 years. This information is incorporated into BoM's flow forecasting models and is an input that assists them in deciding when to issue a flood warning or flood alert.

5 JUNE 2016 FLOOD EVENTS

5.1 Known data acquisition issues during June 2016 floods

(a) As would normally be expected there were a number of data acquisition issues and extended data delays during the June 2016 flood event, caused by issues related to the floods. These sites are not specifically designed for the purpose of flood gauging and are therefore prone to failure in flood events. Hydro Tasmania ceased publishing any data that was inaccurate as a result of these issues once the inaccuracies were identified. Once issues were resolved where possible, the provision of information recommenced. In some instances this was not possible, for example, the monitoring station at Ouse below Staff House Creek was completely washed away in the floods. The specific issues which Hydro Tasmania is aware of are set out in the following section.

5.2 Data communications delay or failure

(a) Several sites experienced extended data delay or unavailability due to communications.

  (i) Iris River at Middlesex Plains. Data was unavailable throughout the flood event (peak). Communications resumed several days later without Hydro Tasmania intervention. It is assumed that the Telstra 3G service was unavailable.

  (ii) Meander River at Deloraine communications stopped on Monday morning 06/06/2016. The issue was determined by Hydro Tasmania staff on site to be a 3G modem. Modem was reset and data transmission resumed Monday afternoon.

5.3 Level instrument/data issues or failure

Several sites experienced level data failure during the event:

(a) South Esk at Llewellyn. The water level instrument which relies on a differential gas pressure measurement developed a leak at high level (pressure). An under-recorded flood peak was returned by the instrument.

Due to the floods, this was difficult to identify and was detected and advised by BoM on Tuesday Morning 7 June 2016. Hydro Tasmania staff travelled from Hobart and rectified the issue around midday.

(b) Ouse at Staff House Creek. The site was completely destroyed (washed away) before the flood had peaked. See photos at Annexure A.

(c) Ouse River at Ashton. Nearing the peak of the flood (Monday 01:30 pm) an electronics cable was damaged by debris causing the instrument to stop. Hydro Tasmania staff gained access to the site on Tuesday morning 07/06/2016 and rectified the problem.

(d) Ouse River at 3B Weir. The water level instrument which relies on a differential gas pressure measurement developed as issue at high level (pressure), assumed to be a gas leak. An under-recorded flood peak was returned by the instrument. The issue was detected post the flood peak and repairs carried out in the following weeks by replacing the water level sensor.

(e) Mersey River at Liena. The water level instrument float became stuck in the well after the flood peak had passed and the level was receding. The float remained stuck until access to site was gained on 22 June 2016 via an alternative route.

(f) Shannon River at St Patricks Plain. The water level instrument float reached its maximum level and hit the bottom of the recorder bench close to the flood peak (within 100mm). Correct values resumed once level dropped below the bench height.

(g) Lake River at Parknook. The water level instrument float became partially caught near the flood peak (within 300mm). Data continued throughout the flood event but with some error.

(h) Fisher River above Lake Mackenzie. An instrument cable was damaged by debris around midday on Sunday 5 June 2016 and data stopped. The site required a helicopter trip and was repaired on 10 November 2016.

5.4 Impacts of the floods on accuracy of future water monitoring data

(a) As a result of the June floods a large number of Hydro Tasmania’s river sites have experienced significant river section change. Accordingly, there will be an increased uncertainty in the high flow rating curve relationships until new high stage gaugings are obtained over the coming years.

(b) During the June 2016 flood at a number of locations the high river levels exceeded the rating curve (flow) relationships that Hydro Tasmania had previously developed. Therefore flow data was unavailable from the time the level exceeded the top of existing rating curve until these were manually extended.

(c) This issue became apparent to Hydro Tasmania on Monday morning 6 June 2016 and “emergency” extensions were completed by early Monday afternoon.

ANNEXURE A

PHOTOS OF OUSE BELOW STAFF HOUSE CREEK – PRE AND POST FLOOD

TERM OF REFERENCE 5: TRANSITION FROM RESPONSE TO RECOVERY

The effectiveness of transition from response to recovery in the week following the June floods; including capacity and priorities for infrastructure repair, and immediate assistance payments.

1 DAMAGE TO HYDRO TASMANIA'S ASSETS AND IMMEDIATE RESPONSE

(a) In the week after the floods, Hydro Tasmania's efforts were focussed on assessment of damage to our assets, making all impacted sites safe, and ensuring functional access to all operational sites. Production and Maintenance staff based in the north of the state took the lead in this effort, and liaised closely with staff from local councils, Department of State Growth and Forestry Tasmania. To coordinate our flood recovery efforts, Hydro Tasmania nominated a senior resource as a flood recovery coordinator, and allocated a project manager to the task of commencing repair works.

(b) The flood recovery coordinator collated all the damage assessments from the affected regions and produced a single register of all affected assets and sites and developed cost estimates for repair works to restore functionality. A simple prioritisation process was then applied to the register of sites based on site criticality, production impacts, safety and other factors. The result of this assessment was a list of over 100 affected sites rated as high, medium or low priority for repair.

(c) Hydro Tasmania's assets sustained around $4 million worth of damage, mostly caused from inundation, debris damage or high flow scouring and eroding earthen structures.

2 LONGER TERM REPAIRS

(a) Most high priority repairs were completed in the four months following the flood, and focus now moves to remaining medium priorities. We have spent over $2 million on repairs to October 2016. It may be some time before the lower priority repairs are completed. These repair works are being funded out of our normal capital and operating budgeting arrangements.

3 HYDRO TASMANIA'S INTERACTIONS WITH OTHER AGENCIES

(a) Hydro Tasmania has continued to work closely with other agencies involved in the flood recovery effort.

(b) In particular, we had representation on the Tasmanian Flood Recovery *Infrastructure Recovery Planning Meetings* coordinated by Department of Premier and Cabinet and SES from July onwards.