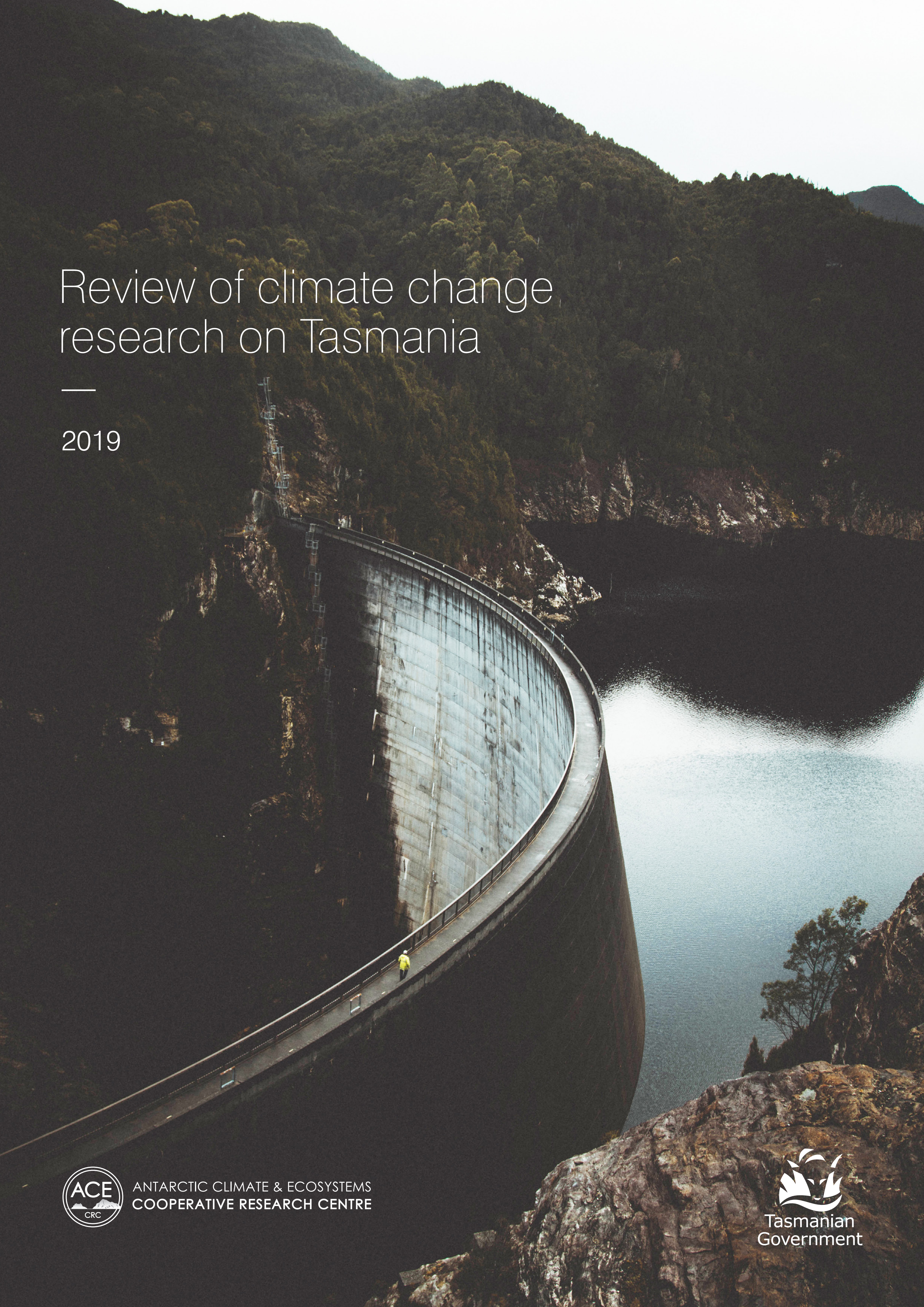
Review of climate change research on Tasmania

2019



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Executive Summary

Tasmania draws strongly on the natural environment for many sectors of its economy, including agriculture, energy and tourism. Climate change affects the risks of natural disasters such as bushfire, drought and energy security. Research has already shown that Tasmania has already been affected by climate change and has economic impacts. Relative to Australia and many other areas of the world, climate change impacts are likely to be milder in Tasmania and could present both adverse and beneficial economic outcomes.

There has been a broad range of climate related projects carried out for the state of Tasmania. Along with the relatively well known Climate Futures for Tasmania Project, this review has identified 27 major projects and a further 50 complementary projects related to climate change in Tasmania. These projects include studies of general changes to climate, climate extremes, water supply and resources, agriculture, biosecurity, effects of fire, and the incidence of Ross river virus. These research activities have resulted in a suite of comprehensive reports that have informed Tasmanian communities, industry, and state government. Economic analysis, due to be released in early 2018, shows that the state has already benefited from this information.

There are 12 climate change research projects currently underway that are using the latest generation of climate models, which will be completed in the next 12 months. These are significant investments that can be used as the basis of the new research and information on climate change in Tasmania.

Tasmania experienced an extra-ordinary dry spring in 2015 and wet autumn in 2016. The dry spring directly led to significant bushfires and low water-yields. Emergency service responses to the bushfires cost $55m. The dry spring had a significant impact on Hydro Tasmania. The wet autumn of 2016 resulted in extensive, devastating flooding that cost 3 lives and $180m in damages. Together these three events (i.e. bushfire, drought and flood) cost the state about $300 million, or 1% of gross state product. Evidence shows that the dry spring was more intense through rising greenhouses gases in the atmosphere and indicates that climate change is already adding to the costs of natural disasters in Tasmania.

Over the last ten years there have been a significant number of developments in the analysis of climate model simulations and also in the availability of new simulations for Tasmania. There is a new recognition that natural disasters magnify the consequences of climate change. There are also new methods and approaches for examining various questions, including climate impacts on human health (e.g. heat stress, mortality), agricultural supply chains and the financial costs of climate change impacts.

The gaps identified in this review are derived from: recent consulting reports to Hydro Tasmania; stakeholder engagements; surveys carried out by the Department of Premier and Cabinet's Tasmanian Climate Change Office; Tasmanian State Natural Disaster Risk Assessment workshops; and a meta-analysis of the climate change reports, research papers already completed and listed in Tables A1 to A5 in Appendix A.

Water underpins many of the activities in the state and is critical to energy security and the future of agriculture. Tasmania is still vulnerable to seasonal variations, with significant interannual variability in rainfall and temperature. Due to the topographic relief, floods can (and do) cause major damage to private and public infrastructure. Since the last climate impacts assessments, new water infrastructure (namely the Tasmanian Irrigation scheme) has been put in place. The sensitivity of this infrastructure to certain types of climate extremes could be assessed.

Coincident and compounding extreme events have not been considered in any of the earlier work. How the frequency of coincidence will be affected by climate change has led to new questions about their relationships and impacts. Questions arising around the coincidence of bushfire with either flood, drought, or heatwave are a few examples.

Agriculture is currently growing at 8% per annum, faster than the other sectors of the state economy. The Climate Futures for Tasmania Project only covered dairy and wine grapes in detail (about $415 million of the state farm gate value for 2015-2016 year), thus the remaining 80% of this sector is effectively un-assessed and could be expanded.

Biosecurity and invasive pests are a concern for Tasmanian agriculture and also the state's natural assets. The potential for damaging agriculture pests to establish in Tasmania as a result of climate change has not been adequately assessed. New analytical methods for pest detection, a better understanding of pest life cycles and new, more reliable projections could all be combined to estimate the emergence of viable populations in the different regions of the state. Such information is crucial for policy development in this space.

Currently tourism to Tasmania directly and indirectly generates $2-3 billion, about 10% of the state's gross state product. Tourism is known to be negatively influenced by natural hazards such as bushfires and floods. The change in bushfire risk across the state has already been assessed, with an extended, more detailed study of the Tasmanian World Heritage Area. However, there is a need to assess more broadly how natural hazards of all kinds (heat waves, storms, floods) will affect Tasmania's unique and highly valued biodiversity, and if this is likely to impact on tourism opportunities in the long term.

The World Health Organisation (WHO) has recently identified the projected changes in climate as being "overwhelmingly negative" (World Health Organization, 2017). The research community has also recognised climate change as "the biggest global health threat of the 21st Century" putting the "lives and wellbeing of billions of people at increased risk" representing "an unacceptably high and potentially catastrophic risk to human health" . While broad risk areas have been identified, the health impacts of a changing climate have not been fully assessed, and thus specific issues affecting Tasmania have not been fully identified or researched.

Tasmania is surrounded by ocean. Aquaculture and wild fisheries are about half of the agriculture sector. These areas are likely to grow and increasingly a critical element of the state economy. Climate change (and its extremes) pose a potential risk to food security through increased risks. A comprehensive assessment of the impacts of climate change on potential risk to the marine environment has yet to be undertaken.

Assessments of climate change and its consequences need to be translated into decisions. At present, the pathway between climate change research outputs and decision making is unclear. Tools that can help decision makers utilise the outputs of research are critical to uptake and impact. Decision making by government and businesses is important from a climate change liability and financial risk perspective. Efforts to develop these tools need to be supported to leverage the enormous amount of work that has already been done, and maximise the benefits of any future work.

It is timely to undertake an update of the future climate assessments to increase the understanding of the risks and consequences for the Tasmanian economy. There is a whole suite of new approaches to climate extremes research, new infrastructure and key sectors of the state economy and natural environment that have yet to be assessed, and taken together make a compelling case for a new statewide climate assessment.

A key success of the Climate Futures for Tasmania Program was the extensive outreach and public engagement that was incorporated into the work plan. Sustained, frequent and broad engagement within both the public and private sectors of the economy resulted in awareness and uptake of relevant climate information by decision makers in Tasmania. Since the Climate Future for Tasmania program was initiated some ten years ago, there have been changes to staff in many of the organisations involved, and it would be timely to review this engagement. Engaging dedicated experts to facilitate the interface between science and the stakeholders would be one example of improving on the past. Leverage through other schemes is required to achieve scale to create a program with an enduring impact.

01

Context for review

1.1 Introduction

Climate change is a pressing problem for society and affects all walks of life. The scientific evidence that the climate is changing is clear. The Intergovernmental Panel on Climate Change concluded in its fifth assessment report that "It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century" (IPCC 2013).

Projections of climate change under a high emissions scenario show profound impacts and for some countries very significant costs (Moore et al. 2015). The 21st meeting of the Conference of the Parties (COP21) resulted in the "Paris Agreement" and has given new impetus across 195 United Nations to mitigate for climate change.

Tasmania has some distinct competitive advantages in research expertise relative to other states of Australia in the concentration of the scientific expertise in climate and environment science. This has led to some exemplary projects starting in 2004 through to the present (for example, the Climate Futures Program at the ACE CRC, **Climate Futures Reports**).

Relative to the other states of Australia, projected climate change in Tasmania tends to be weaker or will be observed later. This may mean that associated impacts are lower or are felt later, depending on the sensitivity of the relevant systems. Certain climate change thresholds occur earlier in the tropics and later in the mid-latitudes and polar regions. These thresholds are crossed earlier because of the more stable climate the areas are closer to the equator. While many mid-latitude regions are projected to have a distinct drying trend of up to 40% (IPCC Chapter 12), Tasmania is near the boundary of this zone of projected drying, and is projected to have low or non-significant trend changes in the net annual rainfall (however, seasonal rainfall changes may be significant) and, because Tasmania is an island with a maritime climate, has smaller projected temperature changes by 2100. The projected change is (2.5 to 4.0°C compared with a global change of 3.4 to 6.2°C for the same high emissions scenario).

Even though the relative climate changes are often smaller, the impact of a particular change depends on the sensitivity and vulnerability of that system to change. Assessing the impact of Tasmania to these projected changes requires an assessment of this vulnerability. Climate change will increase the risks of many of the Tasmania's natural hazards and will pose increased threats to Tasmania's current industries (e.g biosecurity). However, the relatively smaller changes could also provide a relative advantage compared to other places and lead to new areas of activity in Tasmania's major economic sectors. Tasmania's major hazards have already been assessed independently in the Tasmanian State Natural Disaster Risk Assessment (TSNDRA) report (White et al., 2016), but the combined risk of all of these hazards, possibly in the form of coincident events, remains as a key gap that requires further investigation. This was identified throughout the TSNDRA process by a range of stakeholders across operational and strategic roles throughout the emergency sector (Remenyi T.A. & White C.J. *pers. comm*.), explicitly mentioned in the treatment options for Heatwave in the 2016 TSNDRA.

01

1.2 Time to update the old advice

In 2015, the Conference of the Parties 21 (COP21) created the "Paris Agreement" which includes the goal of limiting **global warming** to "well below 2 °C" compared to pre-industrial levels and also calls for zero net anthropogenic **greenhouse gas** emissions to be reached during the second half of the 21st century. The global target sets a new policy relevant target (upper bound) on the amount of carbon emissions nations need to adapt to in response to climate change.The goal of zero net anthropogenic emissions also means that every state in Australia will now have to progressively reduce emissions to meet the target of zero net emissions.

In addition to the global agreements from the Conference of the Parties process, there is now greater pressure on the financial sector to satisfactorily account for the risks of climate change (Task force on Climate-related Financial Disclosure **https://www.fsb-tcfd.org/**), motivated by factors such as the direct costs of hurricanes and associated storm surges in the Atlantic. This additional imperative means that nearly all business enterprises that have climate related activities (either on the impacts or on the emissions side) will be increasingly required to assess their climate related risks. There is mounting pressure on organisational boards to ensure future strategy is stress tested against future climate change impacts. However, there is currently limited effort directed into this area, and there is a huge opportunity for Tasmania to be a world leader.

Training in how climate risk may impact policy makers, and how they can use climate information is important at every level and a great opportunity for Tasmania to be a national and world leader. Along with the high concentration of researchers located in Hobart, there is also a growing number of private companies offering services in this space.

The Tasmanian Government has recognised the changing circumstances at state and national level in Australia for managing climate change and has released *Climate Action 21: Tasmania's Climate Change Action Plan 2017-21* (Climate Action 21). This review completes Action 1.1, to *"Undertake a review of climate change modelling and identify research gaps and opportunities"*, the first of the 37 actions listed in Climate Action 21. It has three specific tasks:

- Undertake a review of climate change modelling and identify research gaps and opportunities
- Work with the scientific community, industry and governments to determine priority research projects
- Work on a set of funding scenarios that can magnify the benefit of the climate change research for Tasmania and thus deliver an enduring impact (Appendix A).

It has been a decade since the last Climate Futures for Tasmania project. There have been many advances in the skills of model simulations, impact assessment techniques and new interpretation approaches. This suggests there is a need for some new work.

02 Past Tasmanian climate impacts projects

The Climate Futures for Tasmania project was an extraordinary partnership that delivered downscaled climate change information for Tasmania with unprecedented detail and scope across a range of disciplines. It was designed to understand and integrate the impacts of climate change on Tasmania's weather, water catchments, agriculture and climate extremes, including aspects of sea level, floods and wind damage. Through complementary research projects supported by the project, new assessments were made of the impacts of climate change on coastal erosion, biosecurity and energy production. In addition, the project included the development of decision support tools to deliver climate change information to infrastructure asset managers and local government.

Climate Futures for Tasmania achieved this broad interdisciplinary scope through a multi-institutional collaboration between twelve core participating partners drawn from government, research and industry sectors at both state and national level. It achieved impact by ensuring that project activities were driven by the information requirements of end-users and local communities.

There were three primary objectives for Climate Futures for Tasmania:

- To produce fine-scale projections of climate over Tasmania based on a range of credible scenarios for global greenhouse gas emissions;
- To derive from the projections key climate variables of most importance to diverse industries, utility and service providers, planners and the community;
- To inform industry, utility and service providers, the community and government on the range of expected values for key variables under alternative scenarios of greenhouse gas emissions. Use these results to facilitate effective adaptation to the most likely climate futures for Tasmania.

This established the basis for the project model with three main activities derived from the primary objectives:

- Climate modelling to produce new simulations;
- Targeted analyses and interpretation of the new simulations;
- Communication and engagement with stakeholders and end-users.

The project was divided into the five key work areas of climate modelling; general climate impacts; water and catchments; impacts on agriculture; and extreme events (Figure 1). However, the analyses and the results were also frequently co-designed and co-produced with stakeholders. No stakeholder was confined to the outputs from one component nor were the results of any component necessarily only of interest to an exclusive stakeholder or group of stakeholders. This successful project model was subsequently adopted by similar projects in other states (see Section 4).

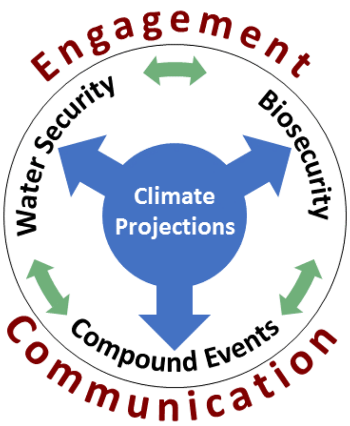

FIGURE 1: Climate Futures for Tasmania targeted the four key environmental sectors of the state economy, namely: general climate trends, water and catchments, extreme events, and agriculture. The project engaged with next users and end users to build end-to-end relationships and thus transformed the understanding of climate change on Tasmania and supported decision making across the state.

In order to achieve the objective of informing stakeholders and end-users the project had a strong emphasis on outputs. Five technical reports on the key work areas, accompanied by 5 plain-English companion summaries, formed the core outputs. These reports together with two supplementary technical reports on specific extreme events are summarised in Table A1 in Appendix A. Further project outputs included additional peer-reviewed reports, journal articles conference presentations, flyers and fact sheets, climate model output and derived data products, as well as information delivery and feedback through stakeholder workshops and briefings to government.

Following the completion of the project in 2011, the partnership between ACE CRC and the Tasmanian Climate Change Office (TCCO) and the process of stakeholder engagement has continued. In collaboration with stakeholder groups, gaps in the analysis of the original project were identified. This led to numerous follow on studies utilising the original project climate model output and following the same methods of targeted information delivery. For example, the scope of the original project did not encompass the impact of climate change on ecosystems, but through participation in the National Environmental Research Program Landscape and Policy Hub the Climate Futures for Tasmania regional climate model output was applied to a range of projects such as Climate Projections for Ecologists and the Tasmanian Future Fire Danger climatology. The various follow on projects are also summarised in Table A1 in Appendix A.

The legacy of the Climate Futures for Tasmania project is broad. Beyond the series of reports, tools and datasets that it produced, there is a long and still growing list of reports and peer-reviewed publications by external data users. The model of government-research-industry partnership with stakeholder engagement and information delivery has been adopted by later projects in other states, such as The New South Wales and Australian Capital Territory Regional Climate Modelling Project (NARCliM).

03

Current Tasmanian projects

There are a number of projects underway in Tasmania that build on, or are complementary to, the Climate Futures for Tasmania project. These are listed in Table A2 in Appendix A. The ACE CRC is currently engaged with Wine Australia to assess changes in the frequency and intensity of large-scale climate drivers and identify weather risks particularly important to grape growing. To carry out this assessment, new high resolution climate projections for southeastern Australia are being produced by the CSIRO using their Conformal Cubic Atmospheric Model (CCAM) model. These projections represent a significant enhancement of the Climate Futures for Tasmania output, utilising Climate Model Intercomparison Project version 5 (CMIP5)[1] as the global driving data and improvements to the representation of precipitation and other processes in CCAM.

The output from the new simulations will be available from early 2018 and are likely to form the basis of most analyses of regional climate change in southeastern Australia (Victoria and NSW governments and researchers are already interested in sharing this resource) until CMIP6 data are available. However, projections are being produced only for the Representative Concentration Pathway (RCP)[2] 8.5 high emissions scenario. Future work commissioned by the Victorian government will run the same set of simulations using the RCP 4.5 scenario, filling part of the gap in understanding the range of possible pathways for climate change (see also Section 4). Producing further projections based on the RCP 2.6 scenario would provide a means for quantitative comparison of relative impacts of each emissions scenario and identifying the benefits of pursuing the policy relevant emissions scenario associated with 2°C of global warming.

The Reanalysis for Tasmania project, a partnership between ACE CRC and the Bureau of Meteorology, is producing a consistent reconstruction of the atmosphere for the Tasmanian region through time at horizontal resolution of 1.5 km. This will provide a high-resolution meteorological and climatological dataset that will allow users to compare weather parameters such as wind, rainfall or temperature (or derived quantities such as fire danger) through time and space to inform emergency management and disaster risk activities. Reanalysis of weather from recent years will be available from April 2019 for the full period, and for limited time periods are available now. This high quality gridded weather data complements the climate projections, providing an improved understanding of current climate and a means of validating regional climate models.

Several tools and reports have been produced to assist in the management and planning of emergency services, built assets and infrastructure, and agriculture with regard to current and future climate. ACE CRC partnered with the University of Tasmania to produce the Tasmanian State Natural Disaster Risk Assessment (TSNDRA) to assess the risk of natural disasters and increase the awareness of emergency risks affecting the state of Tasmania. The majority of the natural disasters considered are climate-related and the effects of climate change on the associated risks were included. However, the report identified that only isolated events had been considered and that further assessment of the likelihood and impact of the coincidence of multiple extreme events should be undertaken.

1 The Coupled Model Intercomparison Project phase 5 archive (CMIP5) includes a standard set of model simulations that have been assessed as providing plausible projections of future climate change. Models admitted to the CMIP5 archive informed the IPCC's Fifth Assessment Report.

2 In the Fifth Assessment Report (AR5), the IPCC addressed the uncertainty about future rates of greenhouse gas and aerosol emissions using Representative Concentration Pathways (RCPs). The four RCPs (2.6, 4.5, 6, and 8.5 W/m2) represent alternative greenhouse gas concentration trajectories resulting from different climate policies.

04

Climate projections projects at state and national level

4.1 Regional climate modelling projects

In recent years there have been several regional climate impacts projects that have either commissioned or utilised new regional climate projections. There are both national and state level projects, with each project having different approach and focus. A description of each project is provided in Table A3 in Appendix A. Indeed, almost every state has undertaken regional climate projections (total of 9 projects). One of these projects covers groupings of Natural Resource Management areas of Australia in a standard and uniform way (see: **www.climatechangeinaustralia.gov.au**) (see Table A3).

There is an opportunity for greater coordination between the different regional projection efforts to leverage and combine the work to gain greater shared benefit. An analogy is the global climate model field, where there have been successive steps to make the different efforts around the world more comparable and standardised. This has contributed to the development of large comparable multi-model archives that allow assessment and quantification of the different results from different models. The recent workshop on "NextGEN" models lead by the NESP hub is an example of coordination of national and regional projection work. Coordination has advantages, there are many relevant aspects of the regional projections that can be used directly, or leveraged off, for state goals. The strategy for the next generation of national projections is currently being scoped and discussed.

Coordination at the intermediate spatial scale is also being pursued by the COordinated Regional Downscaling EXperiment (**CORDEX**), but this program will not serve all needs (e.g. the initial CORDEX program only provides data at 50-60 km resolution). A coordinated program at the fine scale would provide a wider evidence base for better understanding of risk and uncertainty for all the regions covered.

Assessing these current projects (Table A3) shows that there are three major projects that are immediately relevant to any future climate change assessments for Tasmania. These are the Victorian Climate Initiative, the existing and future efforts of the NARCLiM project and the Wine Australia project. Each of these have simulations that have a domain that extends over Tasmania, and as such are resources that could be leveraged through incorporation of this data in a future project. The simulations for the Victorian Climate Initiative and the Wine Australia project are based on the same model and regions but for two different emissions scenarios. The two different emissions means that two different policy settings can be explored and thus are a very complementary set of simulations. These are two most relevant projects for future climate work over Tasmania in Table A3.

05 Developments and new approaches in climate impacts assessments

Over the last ten years there have been a significant number of developments in the analysis of climate model simulations and also in the availability of new simulations and new types of simulations. Some are developments that have been reflected in the last IPCC assessment reports. For example, the testing of human influence in the observational record, and in particular around the attribution of human influence to changes around extreme events (Bindoff et al, 2013, King et al, 2016 and Karoly et al, 2017). Many of these new developments have been reflected and summarised in Table A4 in Appendix A. Overall there are at least 10 areas in the scientific research and simulations that have emerged in the literature from which policy makers could benefit.

There is a new recognition that natural disasters magnify the consequences of climate change. An example of a coincident event in the Tasmania context is the record heavy rains and record floods in 2016 in Northern Tasmania that resulted in extensive damages estimated to $180 million and the loss of 3 lives. In this instance there were many regions flooding simultaneously (which is unusual in a Tasmanian context).

Another type of extreme are two consecutive events called compound events, such as the winter dry spell in 2015 and the floods in autumn of 2016, that together magnifed the consequences of each other. This is discussed in **Precipitation and Inflow Trends in Hydro Catchments**. Such compounding extreme events have not been considered in any of the earlier work in a changing climate in Tasmania, and have led to new questions about their complex relationships and impacts. Similar questions arise around the incidence of fire and flood, fire and droughts and other extremes.

Along with a new focus and new methods in coincident and compounding extremes, there are also new methods and approaches for examining various questions, including climate impacts on human health (e.g. heat stress, mortality), agricultural supply chains and the financial costs of climate change impacts.

Climate change projections feature intrinsic uncertainties, including: the emissions pathway the globe will follow; imperfect knowledge of natural climate variability; and different mechanisms driving change, represented as differences between global climate models. Therefore, there is the opportunity to examine new climate model simulations with more recent configurations to uncover the new insights they may have for Tasmania's future climate. New simulations of the changing climate under future emissions scenarios will be available in 2018 through **CMIP6**. However, these are unlikely to be validated, accessible and useful until late 2019 at the earliest. They will act as the driving inputs to the next generation of regional scale models, but this work will not take place until sometime after 2020. In the meantime, the host of resources (listed in Tables A1-A4 in Appendix A) can be leveraged to underpin future studies.

The new simulations, especially those that include ensembles that enable insight into the scientific drivers of particular extreme events, increase our capacity to more fully understand the uncertainty and the changes in risk for the future climate and the changes in risk that has already occured. New approaches using massive ensemble simulations provide insight into the possibilities from projects like **Weather@home** and hosted in Hobart (Black et al, 2016).

The combination of new approaches (Table A4) to the understanding of extreme events and the emergence of climate change signals, combined with new models and simulations, makes it timely to undertake a re-examination of the future climate and what its consequences are for the Tasmanian economy.

06

Gaps in past assessments

The largest gaps relevant to the Action 1.1 of Climate Action 21 are across key sectors of the state economy, its natural environment and the state infrastructure. Tables A1 to A4 in Appendix A detail the past and current work being undertaken in Tasmania and Australia, with Table A5 summarising the gaps in the science that remain. While the number of projects that have been completed is large (> 75 projects) and have covered many aspects of the state economy, there are still some very significant aspects of the Tasmanian state economy that have not been considered. The gaps identified below are derived from recent consulting reports to Hydro Tasmania, from stakeholder engagements, surveys carried out by TCCO and a meta-analysis of the climate change reports, research papers already completed (all listed throughout Appendix A).

Water underpins many of the activities in the state. Tasmania is relatively water rich, with 12% of Australia's total water supply, but less than 1% of Australia's land area (Bennett et al 2010). There has been new infrastructure that is sensitive to changing climate (e.g. the $220 million investment in **Tasmanian Irrigation Scheme**). Energy security is also an important aspect of the state economy (**Tasmania Energy Security**) and this was brought sharply into focus by the low rainfalls in Spring of 2015, and the devastating floods in Autumn of 2016. Tasmania is vulnerable to rainfall variations in successive years, as well as intense short period extreme events. Past projections concluded that the annual rainfall was unlikely to change significantly over the coming century, but that there would be significant changes in the seasonal distribution of that rainfall (Grose et al, 2010). Tasmania will remain vulnerable to seasonal variations in a changing climate and changes in the frequency of extreme rainfall and floods.

The current modelling efforts (such as the outputs currently available) give sufficient knowledge of longer term rainfall events, (i.e those of 1 day or longer) which are excellent for estimating broad scale, multi-day flood impacts. General information about projected changes to rainfall, including extremes, is given in current projections products. Also, some preliminary guidance on infrastructure planning in light of climate change is given in the Australian Rainfall and Runoff (**AR&R**) guidelines. However, there is no specific guidance for Tasmania with relation to the specifics of the State's infrastructure and climate projections.

Agriculture (together with aquaculture) is another key sector of Tasmanian economy. Agriculture is currently growing at 8% per annum, faster than the other sectors of the state economy. The Climate Futures for Tasmania project only covered dairy and wine grapes in detail (about $415 million of the state farm gate value for 2015-2016 year) (Holz et al., 2010) and thus the remaining 80% of the agricultural sector has effectively not been assessed for future climate risks, although there is additional adaptation work being undertaken by Department of Primary, Parks, Water and Environment. One approach to prioritisation of the agriculture sector would be by economic turnover, and this would suggest a climate impacts analysis for meat and livestock with a value of $451 million, (beef $306 million, lamb and mutton, $88 million, and other livestock at $57 million) as a first priority followed by other agriculture including fruit and vegetables. Further consultation is required to those agriculture sectors that are sensitive to climate change impacts or where there areas of growth from climate change.

Bio-security and invasive pests are a concern for Tasmanian agriculture and also the state's natural assets. Tasmania is fruit fly free, and this status is worth in excess of $100 million pa to the state. However there are many other damaging invasive species and there has been no systematic assessment across the potential invasive species that affect this sector for climate change (**Harris et al, 2017**). From a policy perspective, an estimate of the time of emergence of viable populations in the different regions of the state is essential information for planning and adaptation.

Tasmania is surrounded by ocean. Aquaculture and wild fisheries account for around half the economic value of the agriculture sector. These areas are likely to grow and climate change (and its extremes) pose a potential risk with the increase risk of disease and reduced recruitment (eg Oliver et al, 2017). A comprehensive assessment of the impacts of climate change for this potential risk has yet to be undertaken.

Currently tourism to Tasmania (directly and indirectly) generates $2.79 billion or 10.7% of the state's gross state product, which is slightly larger than the farm-gate value of agriculture. Tasmania's natural environment is an important part of the tourism sector and is vulnerable to extremes in weather that are enhanced through climate change. An example of this sensitivity is the concern expressed by tourists and subsequent fall in visitor numbers after the bushfire in Tasmania's World Heritage Area (Press, 2016). The risk of bushfire has already been assessed across the state and in the Tasmanian World Heritage Area (Report to TCCO and NESP). However, there is a need to assess more broadly how climate extreme events (heat waves, storms, floods) will affect Tasmania's unique biodiversity. Many questions concerning the diversity and stability of natural ecosystems need to be addressed, including the potential for the changing incidence of heat waves and precipitation to cause both gradual and extreme impacts on Tasmania's rich biodiversity.

With regards to human health and wellbeing, the World Health Organisation (WHO) has recently identified the projected changes in climate as being "overwhelmingly negative", especially for regions with the poorest infrastructure that have the most limited capacity to adapt, prepare and respond to increased health risks (World Health Organization, 2017). Research has recognised climate change as "the biggest global health threat of the 21st Century" putting the "lives and wellbeing of billions of people at increased risk" representing "an unacceptably high and potentially catastrophic risk to human health" (Costello et al., 2009; Watts et al., 2015). In light of this, it is important to identify the pressing emerging local threats of climate change relating to human health and wellbeing, and conduct a vulnerability assessment of the prioritised issues.

Assessments of climate change and its consequences need to be translated into decisions (either explicitly or implicitly). Tools that help incorporate climate information seamlessly into decision making and policy frameworks is an essential part of the process and has been identified as a gap. Software that has already been developed includes the ACECRC sea level rise estimator, CANUTE and the award winning Pitt&Sherry ClimateAsyst tool. These are examples of tools designed in collaboration with industry to help day-to-day decision making and planning, in this case for civil engineers. These types of tools are missing from most industries toolkit, and would be a high value activity to progress to support operational decisions, strategic long term decisions and policy development activities.

Of all the natural hazards, coastal inundation, and the associated risk of future sea level rise due to climate change, is the most mature and developed in a policy context. An official policy and guidelines exist (**Tasmanian Local Council Sea Level Rise Planning Allowances**) and these have been incorporated into land use assessment and building approval processes by local governments around the State. New science is emerging around the sensitivity of sea level rise from the melt of Greenland and Antarctica and from mountain glaciers (e.g. Church et al. 2013 and Pollard and Deconto, 2016). A recent position analysis from the ACECRC, **The Antarctic Ice Sheet & Sea Level**, summarises the current science of the Antarctic Ice Sheet and its contribution to the sea level rise. There is significant evidence that sealevel rise is significantly underestimated. However in the sea-level rise community, future sea-level and rates of sea-level rise is a contentious issue, because the uncertainty of the underlying science around sea-level rise and in particular the processes and mechanisms required to project future sea-level. From the perspective of the Tasmanian government the most appropriate time to review the current policies and guidelines would be following the more comprehensive assessment of sea-level rise which will come from the sixth IPCC Assessment Report (AR6), due for release in early 2022.

07

Design of climate programs

There are many options open to a new program of climate change assessments. The goals and strategy of a program tie into stakeholder needs but also the legislative and political environment in which it operates - so are somewhat specific to the place and timeline. Practical realities include the cost and availability of new modelling or other analysis, the capacity and mechanisms for taking projections into applied research through to decision-making and policies. There are also many options for structuring the program to make the most of opportunities to leverage effort, avoid duplication and avoid risks. Programs can be judged by at least four measures of success:

1 Scientific credibility - is the information scientifically defensible and rigorous?
2 Salience - is the information relevant to and understood by the target audience?
3 Legitimacy - is the information and process respectful of different stakeholders and recognised as valid?
4 Actionable - can the stakeholders use the information to take actions (e.g. make specific decisions)?

7.1 Scope

TCCO has recently released Climate Action 21. Within this plan there are 6 priorities, 37 actions, and 65 identified sub-actions. These are resourced through a range of mechanisms. There is funding associated with Climate Action 21 research initiatives, which are the subset of actions presented in detail in Table A6 in Appendix A.

7.2 Communication and having policy relevance

The successful transformation of research into policy doesn't occur when the 'researchers get it right', it occurs only when there is a genuine collaboration between policy and research, fostering a mutual understanding across the policy-research divide. Previous successes in Tasmania have been largely driven by policy makers within government having sufficient scientific and domain expertise to champion a research question and solicit researchers input for targeted projects. When policy makers can be engaged and upskilled enough in a particular research domain to design their own research questions, their capacity to provide governance, guidance and input to a project dramatically improves, resulting in research outcomes that are more relevant and usable in a policy context. Similarly, when researchers are upskilled in the needs and demands of policy makers, it improves their ability to tailor the outputs to suit.

The Climate Futures for Tasmania Project had initial guidance from champions within government, but it was the regular meetings with policy makers throughout government that fostered the capacity of the policy makers to understand the science (and the researchers to understand the kinds of outputs required) that resulted in the long-lasting impacts of this research we have observed.

However, even in ideal situations, stakeholder or community engagement is a real skill, requiring significant effort. In the Climate Futures for Tasmania Project, 30-60% of the researchers' time and energy was spent on stakeholder engagement, community outreach and communications. These activities were coordinated by a dedicated communications officer. This role is one of the core reasons for the on-going legacy and success of the *Climate Futures for Tasmania Project*. A future program would do well to learn from the previous programs approach to communications and improve on it wherever possible. Engaging dedicated experts to facilitate the interface between science and the stakeholders would be one example of improving on the past.

Transforming data into a usable form also has another interpretation. Data from the *Climate Futures for Tasmania Project* is open-access, freely available to everyone. However, the data archive is large (~200Tb), stored in a complex data format and requires significant specialised expertise to access, navigate and use. This is a major limitation for government departments trying to access the data for project based activities. In order to improve how 'actionable' the outputs (i.e. bulk-data, derivative-layers, reports) from a future project could be, significant effort must be placed in developing online tools that simplify accessibility and usability for non-expert users. Tools would incorporate functions such as: archive access and navigation; data-discovery and exploration; analysis and visualisation.

7.3 Leverage against grants

In order to achieve the impact, scale and legacy that is desirable, available funding will be best put to use as contributions towards larger, collaborative projects funded through larger programs. There are a number of funding programs that are available, and the relative match of each to achieve the goals of Climate Action 21 are presented in a separate document. These programs offer various levels of opportunity, ranging in size from ~$100k over 12 months, up to >$10m over 10 years. Most of these funding schemes are cross-compatible, and with a dedicated team coordinating proposal applications, many of the proposals could be successful, thus creating a mechanism to create a program with a scale and size such that it has genuine impact.

08

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Appendix A - Tables

TABLE A1: Core products (reports and other tools) that were created by the Climate Futures for Tasmania project and subsequent state projects, and their applicability and coverage of the relevant climate indices, extremes and regions of Tasmania that were covered by this portfolio of research projects.

Product (or tool)	Sector or risk area	Region	Provider	Availability	Climate models and ancillary models	Summary	Gap Analysis
General Climate Impacts Technical Report, 10/2010	General	Tasmania	Climate Futures /ACE CRC	http://climatefutures.org.au/publications/climate-futures-for-tasmania/general-climate-impacts-technical-report-2/	CCAM simulations hosted in CMIP3 simulations	Sets out the projected changes to Tasmania's climate during this century, including higher temperatures and changes in rainfall patterns.	Update to new emission scenarios, detection and attribution studies are new, and there are no policy scenarios for the purpose of adaptation (comment is relevant to all of the CFT reports below)
Extreme Events Technical Report, 12/2010	Extremes	Tasmania	Climate Futures /ACE CRC	http://climatefutures.org.au/publications/climate-futures-for-tasmania/extreme-events-technical-report/	CCAM Simulations hosted in CMIP3 simulations	Examines extreme rainfall, temperature and drought events in the Tasmanian context to determine how climate change might alter the characteristics of these events in the 21st century. The summary report also includes information on coastal vulnerabilities, wind hazard and impacts on infrastructure.	Coincidence of extreme events is missing (eg flood and heat wave), health related extremes.
Impacts on Agriculture Technical Report, 12/2010	Agriculture	Tasmania	Climate Futures /ACE CRC	http://climatefutures.org.au/publications/climate-futures-for-tasmania/impacts-agriculture-technical-report/	CCAM Simulations hosted in CMIP3 simulations	Sets out the impacts on Tasmanian agriculture from projected climate change. The report examines the key climate indices of frost, drought, chilling and growing degree-days, and focuses on the key agricultural sectors of perennial horticulture, pasture production, grain crops, wine and issues around biosecurity.	Biosecurity and introduced pests could be covered more comprehensively. More detailed assessment of changing productivity and phenology relevant to particular agricultural sectors and regions.
Climate Modelling Technical Report, 12/2010	General	Tasmania	Climate Futures /ACE CRC	http://climatefutures.org.au/publications/climate-futures-for-tasmania/climate-modelling-technical-report/	CCAM Simulations hosted in CMIP3 simulations	Sets out in more detail the performance of the model simulations in reproducing the Tasmanian climate and assesses the likelihood that the simulations accurately project future climate change for Tasmania.	Greater evaluation of some key results, drying in the areas of high elevation, more evaluation of model trends and role of human influence.
Water and Catchments Technical Report, 12/2010	Water resources/ Energy	Tasmania	Climate Futures /ACE CRC	http://climatefutures.org.au/publications/climate-futures-for-tasmania/water-catchments-technical-report/	CCAM Simulations hosted in CMIP3 simulations	Sets out projected river flows, to 2100, for more than 1900 subcatchments in 78 river catchments that cover more than 70 per cent of the State by area. The future operations of Tasmania's hydro-electric system and 14 major irrigation storages were also simulated to 2100.	Coincident events could be covered in this work, particularly around high and low rainfall with other climate indices (heat waves).
Extreme Tide and Sea-level Events Technical Report, 1/2012	Extremes	Tasmania	Climate Futures /ACE CRC	http://climatefutures.org.au/publications/climate-futures-for-tasmania/extreme-tide-sea-level-events-technical-report/	CCAM Simulations hosted in CMIP3 simulations	Describes the development of spatial maps that provide a basis for the investigation of the possible impacts of future climate change due to sea level rise and changes in weather conditions, and will provide information for subsequent coastal assessments around Tasmania	Update with the newer estimates of sea-level extremes curves from new simulations based on new sea-level allowances (from CSIRO) for Tasmania.

TABLE A1 CONTINUED

Product (or tool)	Sector or risk area	Region	Provider	Availability	Climate models and ancillary models	Summary	Gap Analysis
Severe Wind Hazard and Risk Technical Report, 2012	Extremes	Tasmania	Geoscience Australia, Climate Futures /ACE CRC	http://climatefutures.org.au/publications/climate-futures-for-tasmania/severe-wind-hazard-risk-technical-report/	CCAM Simulations hosted in CMIP3 simulations	Investigates the severe wind hazard and risk to residential buildings in the Tasmanian region, both under current climate and also for two 21st century climate change scenarios. The report examines trends in severe wind hazard and risk in the Tasmanian region, and has laid the foundation for the exploration of whether the community and government believe the risk is acceptable or if adaptation strategies are required.	
NERP Landscape and Policy Hub 2011-15	General	Tasmanian Midlands, Australian Alps	UTAS, Climate Futures /ACE CRC, ANU, Murdoch, Griffith, Charles Sturt	https://www.nerplandscapes.edu.au	CCAM Simulations hosted in CMIP3 and CMIP5 simulations	Developed a range of tools, techniques and policy pathways to help planners and environmental managers make decisions, focusing on two case study areas. These tools are designed to help managers consider the multiple impacts of human and natural influences on biodiversity over entire regions, and identify where they can most effectively intervene to protect and improve natural values.	
Future Fire Danger, 10/2015	Emergency services management	Tasmania	Climate Futures /ACE CRC	http://climatefutures.org.au/publications/climate-futures-for-tasmania/future-fire-danger/	CCAM Simulations hosted in CMIP3 simulations	Produced with funding from the Natural Disaster Resilience Program, this report assesses regional changes in fire danger in Tasmania through to the year 2100 under a high emissions climate change scenario.	Attribution of climate change driven component, and scientific reasons for the Spring advancement of high fire danger.
The Potential Impact of Climate Change on Victorian Alpine Resorts, 2016	Tourism	Victorian Alpine Region	Climate Futures /ACE CRC	http://climatefutures.org.au/publications/potential-impact-climate-change-victorian-alpine-resorts/	CCAM Simulations hosted in CMIP5 simulations	Assessment of the viability of snow making under climate change. Assessment of the changes projected to occur in temperature, precipitation and snow cover at each of the six Victorian alpine resorts including shifts in the timing and duration of the ski season.	
The Impact of Climate Change on Weather Related Fire Risk in the TWWHA, 3/2017	Emergency services management	Tasmanian Wilderness World Heritage Area	Climate Futures /ACE CRC		CCAM Simulations hosted in CMIP3 simulations	Assessment of future changes to fire danger indices used operationally by fire managers in the Tasmanian Wilderness World Heritage area. Changes to the frequency and extent of dry lightning outbreaks and changes to weather patterns in the Tasmanian region are also investigated.	Ambiguity in changes to lightning fire incidence given changes in both lightning and soil dryness regimes

TABLE A1 CONTINUED

Product (or tool)	Sector or risk area	Region	Provider	Availability	Climate models and ancillary models	Summary	Gap Analysis
An Assessment of the Viability of Prescribed Burning as a Management Tool Under a Changing Climate, 2017	Emergency services management	Tasmania	Climate Futures /ACE CRC		CCAM Simulations hosted in CMIP3 simulations	Investigates seasonal and monthly changes in the climate variables that determine when prescribed burning can be applied, the frequency and distribution of daily weather patterns associated with atmospheric instability and extreme fire danger, and changes to broad vegetation types that may result from the interaction between climate change and frequency of burning.	
Alpine Resorts Sector Vulnerability Assessment, 5/2017	Tourism	Victorian Alpine Region	SGS Economics and Planning, Climate Futures /ACE CRC		Review of many studies employing multiple models	Two part report comprising a literature review of climate science relevant to climate change in Australian Alpine regions and an assessment of climate change impacts on alpine region economies and communities, adaptation options for alpine resorts and possible adaptation pathways.	
Hobart City Council	Local Government, Infrastructure	Hobart City	Climate Futures /ACE CRC		CCAM Simulations hosted in CMIP3 simulations	Summarised climate model outputs producing data products directly relevant to council operations such as engineering projects.	Means to deliver these reports for many councils on demand and automated in a standard way.
Tasmanian Emergency Volunteer Network	Emergency services management	Tasmania	Climate Futures /ACE CRC		CCAM Simulations hosted in CMIP3 simulations	Investigated the impacts of a changing climate on emergency service volunteer resources in Tasmania. Determined the expected requirements of the emergency services volunteer workforce given the projected frequency and severity of climate hazards (e.g. future fire danger, future heat stress, future rainfall runoff intensity) in the context of projected demographic changes in Tasmanian municipalities.	

TABLE A2: Current projects and products under development by research groups in Tasmania, and tools currently available, their applicability and coverage of the relevant climate indices, extremes and regions of Tasmania are covered, and potential Gaps in current work or the opportunity that could be available to the Tasmanian activities.

Product (or tool)	Sector or risk area	Region	Provider	Availability	Climate models and ancillary models	Summary	Gap Analysis and opportunity
Australia's Wine Future	Agriculture	Australia	Climate Futures /ACE CRC	Active	CCAM Simulations hosted in CMIP5 simulations	Providing high resolution climate information to the wine regions of Australia, assessing historical and future changes in the frequency and intensity of large scale climate drivers and identifying weather risks particularly important to grape growing. Further outputs to include regionally relevant adaptation options to improve the sustainability of each wine region as climate conditions continue to change.	High resolution regional climate projections produced can be utilised in further studies. Projections only for high emissions scenario RCP 8.5. Add in a low emission scenario like RCP 2.6.
Reanalysis for Tasmania	General	Tasmania (part of an Australia-wide project)	Climate Futures / ACE CRC, Bureau of Meteorology	Active. Initial analysis dataset delivered 10/2016. First tranche of high-resolution data product due 04/2018; full dataset due 04/2019	ACCESS-C/ ACCESS-R	Producing a consistent reconstruction of the atmosphere for the Tasmanian region through time at horizontal resolution of 1.5 km. It will provide a high-resolution meteorological and climatological dataset that will allow users to compare weather parameters such as wind, rainfall or temperature (or derived quantities such as fire danger) through time and space to inform emergency management and disaster risk activities.	High quality gridded weather data complements climate projections for understanding of current climate and validation of regional climate models
TWWHA Climate Change and Bushfire Research Initiative	Emergency services management	Tasmanian Wilderness World Heritage Area	Climate Futures /ACE CRC	Active	CCAM Simulations hosted in CMIP3 simulations	Updating the FIRESCAPE-SWTAS fire regime and vegetation dynamics model. The updated model will have improved fire dynamics over an expanded spatial area and will test the effectiveness of the Parks and Wildlife prescribed burning strategy under climate change projections.	Expertise acquired will provide capability to assess future lightning fire ignition efficiency, as raised in preceding TWWHA fire danger report
Tasmanian State Natural Disaster Risk Assessment, 2016	Emergency services management	Tasmania	UTAS, Climate Futures /ACE CRC	http://www.ses.tas.gov.au/h/em/risk-mgmt/tsndra	Review of existing studies, datasets and observations	An assessment of the state level risks associated with bushfires, storms, severe weather events, earthquakes, landslides, coastal inundation, heatwaves, and human influenza pandemic. The overall aim of the 2016 TSNDRA is to contribute to disaster resilience by delivering an increased understanding and awareness of emergency risks affecting the state of Tasmania.	Unassessed state level hazards including biosecurity and coincident events

TABLE A2 CONTINUED

Product (or tool)	Sector or risk area	Region	Provider	Availability	Climate models and ancillary models	Summary	Gap Analysis and opportunity
NESP Earth Systems and Climate Change Hub	General	Australia	CSIRO, BoM, ANU, UTas, Monash, UNSW, Melbourne	Active	Enhancing uptake of current projections, and producing strategy for next generation of regional climate projections for Australia	Partnership of earth system and climate change research institutions prioritising research on past and present climate, how climate may change in the future and building the utility of climate change information. Research will be used to generate data, information, products, tools and services for a range of end users, including government, the private sector, non-government organisations, and Australian communities of interest.	Engagement with this body will enhance potential for leverage by coordination with other state and national regional climate change projects
Hydro Tasmania decadal forecasting	Energy	Tasmania	CSIRO, Climate Futures /ACE CRC, Hydro	Active	Climate Analysis Forecast Ensemble system (CAFE)	Hydro Tasmania and CSIRO have entered into a multiple year contract to investigate probabilistic forecasting of likely water yields into the Tasmanian hydro-generation system over a 1 10 year planning horizon. This will enable improved risk management of Hydro Tasmania's physical and financial position through better alignment of its contract position, future generation capability (hydro and gas) and financial rainfall hedge portfolio.	Outputs from this project could be key inputs into decision making at operational and strategic levels through government and industry. It is highly experimental, so success is not guaranteed, however, if successful it will be a game-changer for Tasmania. .
Victorian Extreme Heat Vulnerability Assessment	Extremes	Victoria	SGS Economics and Planning, Climate Futures /ACE CRC	Proposal submitted	Review of all modelling available	Systematic assessment of the vulnerability of Victoria's economy to heat to enable Victorian governments, and other key stakeholders, to understand current and future risks from extreme heat to Victoria's economy and incorporate this knowledge into decision making.	Climate analysis methodology and decision making framework developed can be applied to Tasmania. High resolution climate data will assess only high emissions scenarios (RCP 8.5, SRES A2).
Queensland Climate Resilient Councils	General	Queensland	Ethos Urban, Climate Planning, Climate Futures /ACE CRC	Invited to respond to RFT. Proposal under development.	Review of all modelling available	Multi-sectoral climate change strategy guideline for Queensland local governments to strengthen internal council decision-making processes to better respond to climate change.	Opportunity is assess the strategy guideline and information delivery model and determine whether there are benefits for Tasmanian local government (NB: work is currently underway)

TABLE A2 CONTINUED

Product (or tool)	Sector or risk area	Region	Provider	Availability	Climate models and ancillary models	Summary	Gap Analysis and opportunity
Development of a Floodplain Risk Assessment Process for Tasmania	Local Government, Emergency Management	Tasmania, Huonville (case study)	UTAS, State Emergency Service, Entura, Climate Futures /ACE CRC	Completed	Review of available data and modelling for the Huonville case study area	Development of a consistent methodological process for the assessment of floodplain risks in Tasmania. The process, developed using a case study centred on Huonville and catalogued as a set of guidelines for use by local Government across Tasmania, is consistent with the Australian Emergency Handbook 7 and the National Emergency Risk Assessment Guidelines. The guidelines provide advice regarding appropriate methodologies for the identification, analysis, and evaluation of risks, including the empirical quantification of the consequences and likelihoods of risks.	Provided a set of guidelines for assessment of floodplain risks in Tasmania for use by Tasmanian local government. Extend the analysis to all flood prone areas of Tasmania as part of guidelines.
Canute - The Sea Level Calculator	Coastal flooding	Australia	ACE CRC, pitt&sherry, SGS Economics and Planning	Available at: **http://www.sealevelrise.info/**	IPCC AR5	Canute provides estimates of the likelihood of flooding from the sea during this century, taking into account sea-level rise and the effects of tides and storm surges. The tool provides Australian coastal planners with critical information on the height and positioning necessary for infrastructure to avoid inundation and erosion under a range of future greenhouse gas emission scenarios.	Renewed interest from engineers for this tool, and could be updated to be part of the practise of the Australian Institute of Engineers.
ClimateAsyst	Infrastructure	Tasmania	pitt&sherry, Climate Futures /ACE CRC	Available at: **http://climateasyst.pittsh.com.au/app/**	CCAM Simulations hosted in CMIP3 simulations	ClimateAsyst is a climate change analysis, risk assessment and communication tool developed with pitt&sherry that can be used by State and local government, emergency services and the general public to assist in the management and planning of Tasmania's built assets and infrastructure in a changing climate.	Update ClimateAsyst to take more layers, potentially for a broader scope than just engineering and coastal indices.

TABLE A3: Current projects and products under development by research groups outside of Tasmania, and tools currently available, their applicability and coverage of the relevant climate indices, extremes and regions of Tasmania are covered, and potential Gaps in current work or the opportunity that could be available to the Tasmanian activities.

Project	Sector or risk area	Region	Provider	Availability	Climate models and ancillary models	Summary	Gap Analysis and opportunity
Australian national climate projections	General	National coverage of NRM areas across Australia	CSIRO	Yes, (see: www.climatechangeinaustralia.gov.au)	CMIP5	The Australian national climate projections work includes Tasmania under the 'Southern Slopes' cluster of NRM regions. This work assessed the latest CMIP5 global climate models, as well as new CCAM and Statistical downscaling to give an assessment of climate change in the region, as well as providing various web tools for exploring projections and accessing datasets. Since the project was national in scope, and the methods were consistently applied to all Australian regions, there is minimal analysis tailored specifically to Tasmania.	There are considerable opportunities to leverage and coordinate with the national projections work, to free up resources for Tasmania-specific research.
NARCLiM 2011-13	General	NSW	UNSW, NSW and ACT Governments	http://climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/	WRF Simulations hosted in CMIP3 simulations	Major project on the national scene, with a high uptake and a high level of application through NSW and ACT agencies. Produced an ensemble of regional climate projections for south-eastern Australia used by the NSW and ACT community to plan for the range of likely future changes in climate. Very comprehensive across variety of climate indices, targeted at the local government region level, with outputs accessible through a portal.	Assess the value of a portal, like that used by NARCLim that allows users access to local area level information and data to improve uptake of available information about climate risk.
Consistent Climate Scenarios Project 2013	Agriculture	Australia	Queensland Climate Change CoE	https://www.longpaddock.qld.gov.au/climateprojections	Statistically downscaled CMIP3 simulations	Provided researchers with 'ready-to-use' Australia-wide projections data for 2030 and 2050 for climate change impacts and adaptation studies in a format suitable for input to biophysical models.	Narrow focus on agriculture.
Queensland Climate Adaptation Strategy 2014-present	General	Queensland	Queensland Department of Science, Information Technology and Innovation, CSIRO	https://www.qld.gov.au/environment/climate/climate-change	CCAM Simulations hosted in CMIP5 simulations	Provides a framework for ensuring an innovative and resilient Queensland that manages the risks and harnesses the opportunities of a changing climate. The Q-CAS is centred around a partnership approach that recognises that climate change is everyone's responsibility, and that a collaborative approach is needed to ensure resilience is embedded in Queensland's diverse economies, landscapes and communities.	Work at an early state, projections do not overlap over Tasmanian region.

TABLE A3 CONTINUED

Project	Sector or risk area	Region	Provider	Availability	Climate models and ancillary models	Summary	Gap Analysis and opportunity
Indian Ocean Climate Initiative 1997-2011	General	Western Australia	WA Government, BoM, CSIRO	http://www.ioci.org.au/about-ioci.html	Statistically downscaled CMIP3 simulations, statistically downscaled CCAM simulations hosted in CMIP3 simulations	Investigated the causes of the changing climate in WA and developed projections of the future climate in WA.	Not relevant now
Murdoch University Regional Climate Modelling 2014-present	General	Southwestern Western Australia	Murdoch University, UNSW		WRF Simulations hosted in CMIP3 simulations	Has developed regional climate modelling capability for southwestern Western Australia, producing projections of regional climate change for mid-21st century.	Relevant to the Wine Australia project.
SA Climate Ready 2011-14	General	South Australia	Goyder Institute	http://www.goyderinstitute.org/research/foundation-research/climate-change/	Statistically downscaled from CMIP5 simulations	Produced a set of statistically downscaled climate projections for SA and regional summary reports providing overviews of the direction of change for the variables for each NRM region for the 21st century.	Focus on water resource availability.
Victorian Climate Initiative 2013-16	Water Resources	Victoria	VIC Government, CSIRO, BoM	https://www.water.vic.gov.au/climate-change/victorian-climate-initiative	CMIP5	Designed to further develop understanding and prediction of climate impacts on water availability to better inform Victorian water resource planning and management. Produced several reports on past climate variability and change, seasonal climate prediction, and future climate and the associated risks to water resources.	Focus on water resource availability, but does not include new simulations for the period of interest.
Wine Australia Project	Wine Industry	Victoria	Climate Futures/ACE CRC/CSIRO	Climate Futures	CCAM Simulations hosted in CMIP5 simulations	Wine Australia has commissioned a major project on the future of the wine growing in Australia through the ACE CRC partnering with CSIRO and others. The project includes new high-resolution simulations (5 km) using the CCAM model that will explore the highly localised climate of wine regions (these simulations are leveraged with new regional climate information for Victoria, see above).	Simulations are general, suitable for Victoria, NSW, South Australia and Tasmania. Could be used in climate futures project in Tasmania

TABLE A4: New climate impacts methods and capabilities. First column is the new research capability, column two is a summary of this capability, the third column is whether the new capability is a service (eg climate projections) or simply a new analysis method. The last column shows when and if the results will be available.

Research Developments	Summary of the new climate impacts capability	Service, output or capability description
Coincident Events	Probability of coincident events: the probability of coincident events is of strong interest as the impacts are greater than each extreme in isolation. Some extremes have well known joint probabilities - such as the strong winds and heavy rainfalls that comes with some types of storms - others are less obviously connected. The coincident extreme events in the summer of 2015-16 (drought, fire, flood, marine heat wave) caused many issues to manage across many agencies. Similar to assessing consecutive events, the assessment of coincident events requires an understanding of the changing probabilities of each type of events and also how they combine.	Analysis, and can be applied to current simulations.
Compounding Events	Probability of compounding events. Extremes that are consecutive can have far larger impacts than if the same extremes are separated in time. For example, the extremely dry spring and summer 2015-16, followed by the extreme wet conditions in 2016 had a range of impacts to the natural systems, agriculture, water security and hydroelectric power generation in Tasmania. Assessing the changing probabilities of each extreme event, and how they may come in sequence, has not been attempted much as yet, and involves some challenges. However, it is likely to have useful applications to assessing impacts and planning adaptation actions. Such an assessment would involve the assessment of past probability and the examination of the changing probabilities of each one in isolation and also in combination.	Analysis, and can be applied to current simulations
Attribution of observed changes	Attribution of causes of climate change trends and extremes can be useful to understand climate change processes, quantify the change in climate risk we have already experienced, and to communicate the importance of human influence to a wide audience. The attribution of human influence in the climate change is directly relevant to the audience, rather than future projections that can be more abstract to the audience. Also, the attribution of climate change to date illustrates the change in climate-related risk that we have already experienced, so can inform current policies and practices, not just long-term strategy. It also informs our understanding of extremes in the near term by providing an updated 'baseline'.	Analysis, and can be applied to current simulations
Attribution of extremes (Fractional Attributable Risk)	The attribution of climate change trends has been pursued for some time, however we now have the emerging field of event attribution that uses the fraction of attributable risk (FAR) concept adapted from epidemiology. The FAR approach illustrates the difference in the odds of a particular extreme that occurred compared to a hypothetical or 'counterfactual' world with no human influence on the climate.	Analysis
Time of emergence	Time of emergence is when the the changes of the mean climate exceeds a measure of the internal variability. For example, when the change in the mean exceeds one standard deviation of the internal variations. The concept allows displays of when the climate change signal emerges from the natural variations.	Analysis
Synoptic weather typing	Analysis of large ensembles of short duration climate simulations can yield statistics on the frequency of extreme weather events. Attribution studies can be conducted by comparing statistics from ensembles incorporating either all known climate forcings, including anthropogenic, or natural forcings only. Recent studies of this nature have been facilitated by the weather@home project in which large ensembles are generated using compute resources donated by thousands of volunteers with home computers. Further extension of these attribution studies can be achieved by subsetting of the ensembles based on classification of synoptic types. In this way changes to the frequency and severity of extreme events associated with particular weather patterns can be assessed.	Analysis from ensembles, weather@home
Fire risk	The use of high resolution regional climate simulation output to calculate gridded projections of standard operational fire danger ratings is well established. In the Tasmanian context this capability has been expanded to include experimental metrics applicable to certain vegetation types where standard ratings are known to be deficient. With the development of a new National Fire Danger Rating System these methods can be updated to provide more detailed and informative projections. Further emerging capabilities exist in the provision of regional climate model output and derived data products as input to operational models for fire management planning such as the Bushfire Risk Assessment Model for assessing fire likelihood and consequence and FIRESCAPE-SWTAS for fire regime analysis and development of prescribed burning strategies.	Analysis/decision making tools
Run off and rivers flows.	The authors of the Australian Rainfall & Runoff national guidelines have recently identified the 'interim guidance' on the allowances for climate change as insufficient, recognising that a resolution will require significant effort. The the Bureau of Meteorology is investigating the feasibility of future studies to address this gap and requesting advice from a selection of national experts, of which a high proportion are located in Tasmania, which could be an opportunity for the state.	New ~1km resolution, convection permitting regional climate model runs. Not available until
CMIP6 simulations	The new set of global climate model simulations (CMIP6) is currently being run and will be bigger and wider ranging than CMIP5. There are also an expanding set of other sources of information to draw on when making climate projections, including the CORDEX project mentioned above but also other targeted modelling projects. A new Sixth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC AR6) will provide a new assessment of the global science and impetus for new regional research. There are new developments that affect the potential framing of projections, including the development of the Paris agreement targets (e.g. to keep global warming to within +2 °C from pre-industrial levels). This gives a specific mitigation scenario with political weight to it, so projections of this target compared to higher scenarios are of interest.	New simulations

TABLE A4 CONTINUED

Research Developments	Summary of the new climate impacts capability	Service, output or capability description
Climate Predictions	There is a major international push for extending beyond seasonal predictions, to produce multi-year to decadal prediction products (i.e. a prediction of the sequence of climate events rather than simply an estimate of the forced climate change 'signal' in the near future). There is potential predictability from slow processes in the ocean, and this can inform probabilistic predictions of near term climate events in certain cases. CSIRO has a major new research program in this field, and there is also research being done at the Bureau of Meteorology and elsewhere.	CSIRO, and limited availability of prediction for Tasmania. Still requires research.
Reliability of information from current and previous climate assessments	Previous assessments of climate change in Tasmania have assessed many important processes relevant to our region, such as broad-scale circulation changes that lead to seasonal rainfall trends, important weather systems that bring heavy rainfall and severe fire weather events, and the storms that add to high sea level events. However there is room for further analysis of the weather systems associated with other extreme events and the processes behind the key projections. This further analysis is required to confirm earlier results Using the current framework and methods in climate change science, these dimensions include: 1. Emissions scenarios 2. The range of possible global climate response to each emissions scenario (the range of suitable global models gives some estimate of this) 3. The range of regional responses to each large scale response (a range of downscaling methods give an estimate of this) 4. The likely effect of natural variability compared to human-induced climate change 5. The possibility of changes not covered within the current modelling framework (e.g. non-linear or 'runaway' changes, climate shocks such as large volcanic eruptions) The recent climate change assessments available for Tasmania cover each of these dimensions to varying degrees. Projections for all the RCP emissions scenarios are presented in the national projections, Climate Futures for Tasmania used a high and a low scenario (A2 and B1). A range of global climate models are used for all assessments, and the process of selecting models for downscaling was fairly thorough in CFT and follow-on work. Natural variability compared to human influence and the possibility of non-linear or abrupt change have been explained in all assessments, but there is the potential for better quantifying these factors and making them relevant to decision-making. A comprehensive or systematic assessment by using different downscaling techniques anywhere in Australia (e.g. the Climate Futures for Tasmania project used a single method), but this has been done overseas (e.g. the NARCCAP program: **http://www.narccap.ucar.edu/**). There is an opportunity to better address this dimension through coordination and leveraging effort between regional studies, i.e. various groups could produce regional projections for all of Australia in a comparable form, rather than each group doing a particular sub-domain of Australia separately	Analysis, many projections available and can be assessed against framework in middle column.

TABLE A5: Gaps in the project work that has been undertaken in the last 10 years. First column is the gap or incompleteness of the earlier projects, column two is a summary of this identified gap, the third column is whether there is a feasible solution.

Identified Gap	Summary of the gap in climate impacts In Tasmanian Region	Feasible solution
Natural Disasters	An understanding of the frequency of natural disasters co-occurring either simultaneously, or within close enough proximity in space or time to become a management issue.	Analyse the frequency of coincident natural disasters and extreme events in the historical record and assess the likelihood of such events into the future. Various types of events could be considered, including dry conditions followed by a sudden onset of heavy rain, coincidence of dry lightning and dry fuels for bushfire risk.
Agriculture	Some general information exists for the main agricultural sectors in Tasmania, but information should be more targeted and incorporate better understanding of the consequences of changes to the timing and frequency of extreme events (eg. heatwaves and frost events). Changes to productivity and phenological changes (timing of life cycle events such as lambing, planting and harvesting dates) need to be better understood and communicated. Earlier work has covered about 20% of the economic value of the agriculture sector for Tasmania, leaving some key products unassessed.	A more comprehensive assessment of the agriculture sector. Identification of the important climate risks in all enterprise types and regions through consultation with industry with the delivery of tools like the crop calendar approach developed by SARDI (Reference).
Natural Systems (biodiversity)	Most research to date has focussed on the impact of changes to mean climate conditions on biodiversity. However, extreme events (heat events, storms, bushfires, floods) are likely to be major drivers of change to natural systems. Modelling has tended to focus on rare and endangered species and communities but should be extended to cover broad vegetation types and common species that determine the structure of communities. Modelling of the potential impact on terrestrial, freshwater and marine ecosystems is still lacking. The focus on species distributions should be extended to improve our understanding of changing ecosystem structure and function.	A statewide assessment of the most vulnerable species and communities is required to help prioritise management intervention (eg. alpine, coastal habitats, fire-sensitive species). A review of existing knowledge of species tolerances and requirements would identify potential for greater use of mechanistic models.
Biosecurity and invasive species	Biosecurity is important for agriculture, forestry, aquaculture and Tasmania's natural values (eg phytophthora). Research into the potential for known pests and diseases to become established under future climate conditions is required, and also the potential threat from the arrival of new species and pests. Research should consider changing climatic conditions and dispersal potential. Some research has been done investigating the arrival of new species in the marine environment.	Models for invasive pests and species exists and using new and past climate simulations allow exploration of the risks posed by invasive species.
Human Health and Community Wellbeing	The health impacts of a changing climate have not been fully assessed in Tasmania. While broad risk areas have been identified through a range of organisations (for example, the World Health Organization, the Global Climate and Health Alliance, and the Australian Climate and Health Alliance), specific issues affecting Tasmania have not been fully identified or researched. There has been some investment in planning and response to the issue of heatwaves through Public Health Services (DHHS), however other issues such as respiratory risks from increased particulate matter and pollen, the mental and social health impacts of extreme events and disasters, increased risks of infectious diseases, and food and water insecurity, have not been addressed at a local level. As per other global research, it is likely these impacts will affect the most vulnerable populations in the Tasmanian community, who are least likely to have resources to prepare and respond to these emerging health threats.	Using global research, identification of the most pressing emerging local threats is needed, followed by a vulnerability assessment of the prioritised issues. Given the political attention given to the state health budget in the recent past, a useful adjunct to this research would be to model these impacts into the future through an economic lens.
Marine Sector	The marine sector of Tasmania has yet to be assessed for the consequences of climate change. Marine industries, including aquaculture, wild fisheries and other industries are an important contributor to the Tasmanian State economy (at least $882 million 2015/2016). There is no known robust assessment of the climate change impacts on Tasmania marine sector that is analogous to the climate future work.	The marine regional climate models (used for downscaling global climate models) are relatively immature. The coastal margins are difficult to model and have had little attention. Investment in basic research in this area is likely to produce strong returns relatively quickly (1-2 years).
State Infrastructure in a changing climate	Extreme events that include bushfire, flood, severe storm, extreme precipitation, heatwave and coastal inundation can affect key state infrastructure and assets. There is new recognition of the how these extreme events can coincide and amplify risk.	Most key infrastructure have been identified, and their point sensitivities are known (eg. coastal sea-level, extreme temperatures) and assessments are feasible with the right partnerships in state business enterprises, local government, and in industry.
Tools for the discovery and support local decision making and planning	There are a range of state and national tools that have been developed to support decision making and planning. Many of these tools could be refreshed and potentially redeveloped to meet end user needs and new information based on new approaches to the analysis of climate data and simulations. Here are some of the tools that provide climate change information, along with other information to support decisions being made for climate mitigation and climate adaptation.	Solutions that are available **Climateasyst** - A tool for engineers **The List** - The Tasmanian State Government's spatial data portal **Coast Adapt** - A national tool developed by NCCARF **Canute** - Sea-level rise tool developed by ACE CRC **Lumen Risk Analytics** - business risk assessment service that includes climate change related risk
Gaps in decision making and science	In order for researchers to be able to influence decision making, a clear map of how decisions are made within each stakeholder's organisation is required to identify where climate science is an input, and what format is most useful.	In Tasmania the most developed organisations need to take the lead and show new entrants into the climate impact assessment space how best to identify where climate information can add value to their business model.

TABLE A6: Climate Action 21 actions directly or indirectly associated with research initiatives.

Climate Action 21 Action
1.1 Undertake research on climate change projections with key industry partners - Undertake a review of climate change modelling and identify research gaps and opportunities - Work with the scientific community, industry and governments to determine priority research projects
1.2 Build our understanding of Tasmania's vulnerability to coincident extreme events and their impacts - Undertake research to understand the complex interdependent relationships between natural hazards and their causes
1.3 Provide sector-specific information on Tasmania's future climate - Deliver tailored climate information and decision support tools for end users such as the wine industry, catchment managers and emergency services
1.4 Support an ongoing commitment to the National Climate Science Centre in Hobart - Support the ongoing activities of the National Climate Science Centre
4.1 Attract investment and jobs using our clean energy advantage - Make climate change projections easily available and accessible for investors Coordinator General
4.5 Support the resilience of small and medium-sized businesses to extreme events by extending the Disaster Planning and Recovery for Tasmanian Businesses project - Deliver resources tailored to specific industry sectors - Conduct workshops with businesses
4.6 Provide information on climate change risks and opportunities to support future decision making for agricultural production - Update the existing Enterprise Suitability Mapping project to incorporate climate change projections
4.8 Provide water surety for irrigation to underpin agricultural productivity in a changing climate - Deliver the five proposed Tranche II irrigation schemes - Investigate the feasibility for a third tranche of irrigation development to connect, modernise and enhance Tasmania's irrigation network Tasmanian Irrigation
4.9 Invest in skills to prepare our industry sectors, regional communities and workforce for a changing climate - Work with industry sectors and regional communities to identify skill needs - Subsidise relevant training
5.2 Help communities understand their exposure to natural hazards - Develop online resources to provide households with information about their exposure to natural hazards
5.3 Work with local government and regional bodies to embed climate change adaptation into strategic and financial decision making - Assess how local government is currently planning for climate-related risks - Prepare tailored climate change projection summaries for each local government area
5.4 Ensure climate change is considered in Tasmanian Government decision making
6.4 Identify additional policies and programs to respond to the potential health impacts of climate change - Deliver policies and programs to build community resilience to population health risks in a changing climate

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