Department of Agriculture and Fisheries – Drought and Climate Adaptation Program

DCAP Project Final Report

Project ID	DCAP DSITI 16.0 Learning from the past – incorporating palaeoclimate data into water security planning
Grantee Name	

Designated Project Leader	Name: Dr Anthony Kiem University of Newcastle
Report authorised by:	Name: Dr Ramona Dalla Pozza Date: 27/06/2017
Report accepted by:	Name: Neil Cliffe Position: Program Manager, Drought and Climate Adaptation Program.

1. Executive Summary

Decision makers in the water sector need to deal with uncertainty about future climate, and changes in catchment conditions. Identifying solutions for hydroclimatic risk adaptation strategies that are both optimal and robust in the presence of uncertainty presents a difficult challenge. The instrumental record is short (~60-130 years), and fails to encompass enough climate variability to allow the calculation of robust statistics around the baseline risk of extreme events (i.e. multi-year droughts, decadal periods with clustering of major flood events). This climate variability is documented pre-1900 in palaeoclimate records from sources such as corals, tree-rings, freshwater and marine sediments. Despite being remote from Queensland, a high resolution and highly correlated palaeoclimate record from the Law Dome ice cores in Antarctica exists (Vance et al. 2015). This record has identified eight mega-droughts (lasting from 5-39 years) during 1000-2009 AD. Most importantly, the palaeoclimate information confirms that the post-1900 instrumental period (i.e. the period on which all water resources infrastructure, policy, operation rules and strategies is based) does not capture the full range of variability that has occurred. Recent work for the New South Wales government (http://climatechange.environment.nsw.gov.au/Impacts-of-climate-change/East-Coast- Lows/Eastern-Seaboard-Climate-Change-Initiative) also shows that, out to 2050 at least, the impacts of natural variability dwarf even the worst-case climate change scenarios (i.e. obtained from Global Climate Models run under the highest emission scenarios).

The objective of this project was to (a) demonstrate the utility of a palaeoclimate proxy approach in producing robust catchment statistics; (b) gain improved insights into the characteristics and risk of hydroclimate extremes in South East Queensland (SEQ) for water security planning and (c) deliver insights and recommendations to SEQ water managers for optimising hydroclimatic risk adaptation strategies and solutions. Refer to **Error! Reference source not found.** for full details on the project background, scope, objectives and expected outcomes/outputs.

The key findings from the project were:

1. Some centuries are drier than others (e.g. there are few dry periods in the 1400s, 1500s and 1800s relative to the 1000s, 1100s, 1200s and 1700s).
2. Although long dry periods are evident in the instrumental period, they are not unprecedented and the longest dry period in the instrumental record for SEQ (8 years from 2000-2007) has actually been matched orexceeded several times prior to 1900.
3. Irrespective of the way you define drought, the instrumental record only includes three of the worst 10 droughts in the last 1000 years and the worst drought that has occurred in the instrumental record is not in the worst five from the last 1000 years.
4. Palaeoclimate data can be used in conjunction with analogue maps developed using gridded data from climatically similar periods in the instrumental record to infer the location and spatial extent of pre-instrumental dry/wet periods. Despite this simple method being demonstrated, future work should focus on verifying the analogue maps via the development of local palaeoclimate proxies or possibly through the use of climate models operating in hindcast mode (see Section 2.2.1 in the final report).
5. Relying on the statistics from one century worth of data (or less) for drought management planning, as is currently common practice, is problematic given that all centuries have a different frequency and duration of dry (and wet) epochs and there is no reason why this will not continue to be the case in the future.
6. The instrumental period is not representative of the full range of past climate variability in SEQ.
7. Irrespective of the multi-year period or drought magnitude being investigated, the probability is always higher when the reconstruction record is used than it is when the instrumental record is used. This demonstrates again that the instrumental record does not properly capture the full range of variability that has occurred or is possible. Also important to note is that, according to the instrumental record certain rare but high impact drought events are not possible (e.g. 5- and 10-year periods associated with 30% less rainfalloverall, 3- and 5-year periods associated with 40% less rainfall overall). However, there is evidence in the palaeoclimate records that strongly suggests these type of events have occurred before and while they are rare the likelihood of them occurring should not be considered to be zero.

Important recommendations from the project include:

- Working with DSITI, Seqwater and other stakeholders to ensure the rainfall reconstructions produced (and the methodology used) are satisfactory (e.g. for the right locations, realistically identify important wet/dry epochs, are suitable for practical application of insights emerging, are suitable for input into IQQM, eWater Source, South East Queensland Regional Stochastic Model (SEQRSM) etc.).
- Completing similar analysis to that presented in Section 2 and Section 3 but instead focussed on wet epochs and flood risk.
- Working with DSITI, Seqwater and other stakeholders to complete objective assessments of the strengths and weaknesses of existing management strategies for each case study location under existing estimates of drought risks based (a) just on the instrumental record, (b) on the instrumental record and insights from the palaeoclimate records and (c) on the instrumental record, palaeoclimate record and future climate projections obtained from climate models.
- Use the statistics from the 1000-year rainfall reconstructions to expand on Section **Error! Reference source not found.** to develop new stochastic rainfall simulations that take into account both instrumental and pre-instrumental variability. This should be done with assistance from DSITI (and other relevant industry/government stakeholders who have access to existing stochastic rainfall simulations – and also the models it is used as input for).
- With assistance from DSITI (and other relevant industry/government stakeholders) use the palaeo-informed stochastic rainfall simulations (from the previous point), in the same way existing instrumental-based stochastic simulations are used, to test the ability of current infrastructure, planning or management strategies to deal with the range of hydroclimatic conditions that have occurred in SEQ over the last 1000 years – and where problems are identified propose and test new or improved infrastructure, planning or management strategies so as to improve water security and drought management. This is the focus of a second ARC Linkage application to be submitted August/September 2017 (led by Anthony Kiem at University of Newcastle) and also two ARC Discovery Project applications that were submitted in March (see AppendixD for further details).
- Use climate modelling to determine the physical climate processes associated with the major instrumental and pre-instrumental droughts identified here in order to better understand the causes of multi-year drought (and also the processes associated with bringing a drought to an end). If the physical mechanisms

behind the onset, persistence, magnitude, spatial extent and termination of drought can be better understood this will aid seasonal to interannual forecasting of drought and give more confidence in in the future projections of how droughts will change under anthropogenic climate change.

- Collect and/or develop local palaeoclimate information for SEQ (as per that proposed on the Croke et al. ARC Linkage application discussed in Section 2.2.2).
- Conduct the other future work associated with ARC Linkage Projects and ARC Discovery Projects discussed in Appendix D.

2. Project Background

Decision makers in the water sector need to deal with uncertainty about future climate, and changes in catchment conditions. Identifying solutions for hydroclimatic risk adaptation strategies that are both optimal and robust in the presence of uncertainty presents a difficult challenge. The instrumental record is too short to encompass enough climate variability to allow the calculation of robust statistics around the baseline risk of extreme events (i.e. multi-year droughts, decadal periods with clustering of major flood events). This climate variability is documented pre-1900 in palaeoclimate records from sources such as corals, tree-rings, freshwater and marine sediments and despite being remote from Queensland, a high resolution and highly correlated palaeoclimate record comes from the Law Dome ice cores in Antarctica (Vance *et al*. 2015). This record has identified eight mega-droughts (lasting from 5-39 years) during 1000-2009 AD. Most importantly, the palaeoclimate information confirms that the post-1900 instrumental period (i.e. the period on which all water resources infrastructure, policy, operation rules and strategies is based) does not capture the full range of variability that has occurred. This high variability is projected to continue - as recent work for NSW government also clearly shows that, out to 2050 at least, the impacts of natural variability dwarf even the worst-case climate change scenarios (i.e. obtained from Global Climate Models run under the highest emission scenarios).

3. Project Methodology

Overall project methodology is as follows:

1. Identify 2-3 case-study catchments – this is informed by (a) where information is most urgently required; (b) hydroclimatic data and hydrological/stochastic model availability; (c) locations where we know there is a strong teleconnection with ocean-atmospheric process that are detected in the Law Dome ice cores (e.g. ENSO, IPO).
2. Collect and pre-process observed historical rainfall data (station-based and AWAP or SILO).
3. Produce and verify the 1000-year annual resolution rainfall history for the 2-3 case study locations.
4. Conduct palaeoclimate-informed drought risk assessment for each case study location (i.e. frequency, duration, magnitude, location/spatial extent of rainfall deficits and surpluses).
5. Use the statistics from the 1000-year rainfall reconstructions to develop stochastic rainfall simulations that take into account both instrumental and pre-instrumental variability. This will be done with assistance from DSITI (and other relevant industry/government stakeholders who have access to existing stochastic rainfall simulations – and also the models it is used as input for).

The methodology used to develop the rainfall reconstructions from the LD_{SSS} record is summarised below:

- The Pearson correlations between annual rainfall (calculated for different 12-month aggregation periods) and Law Dome record (LD_{SSS}) were calculated for the high quality (HQ) gauges used in this study. Note that non-linear methods were also tested and no major differences or improvements in the relationship between annual rainfall and LD_{SSS} were found.
- Pearson correlations between rainfall and LD_{SSS} were also calculated for different Interdecadal Pacific Oscillation (IPO) phases to assess the stationarity and decadal variability of the relationship. The instrumental IPO index is provided by Folland (2008). The IPO index is stratified into phases according to a threshold of 0.5 where an index value greater than (less than) 0.5 is indicative of a positive (negative) phase (Power et al., 1999; Kiem et al., 2003). Following this definition IPO positive phases are 1924-1941 and 1979- 1997 while 1947-1975 is IPO negative. Additionally, we assess IPO phases given in Meehl et al. (2016) which correspond to 1910-1941 and 1971-1995 (positive) and 1941-1971 and 1995-2013 (negative).
- The 12-month aggregation period that provided the highest correlation between rainfall recorded at the HQ gauges and LD_{SSS} was selected.

- 1013-year rainfall records were then reconstructed for each AWAP grid within each catchment and for the 40082 HQ gauge by rescaling the LD_{SSS} record to match the median and interquartile range of the relevant gridded/gauged data. Catchment average rainfall was then calculating by averaging the relevant grids for each catchment.

4. Project Results

4.1 Achievements and Outcomes

1. Reconstructed a 1000 year rainfall history for key locations in SEQ, at both station and catchment-scales, based on palaeoclimate data.
2. Completed a long-term drought risk assessment (e.g. incorporation of palaeoclimate information covering drought frequency, duration, location/spatial extent).
3. Re-evaluated the probability of multi-year drought in the light of insights emerging from the palaeoclimate information.

4.2 Unintended Outcomes

N/A

4.3 Partnership Formation

This pilot project developed a productive partnership between DSITI, Seqwater, the University of Newcastle, and the Antarctic Climate and Ecosystem CRC. The team included:

- A/Prof Anthony Kiem, Centre for Water, Climate and Land (CWCL), School of Environmental and Life Sciences (Earth Sciences) Faculty of Science, University of Newcastle.

- Dr Carley Tozer and Dr Tessa Vance Antarctic Climate and Ecosystem CRC, University of Tasmania.

- Dr Kate Smolders and Ms Wendy Auton, Seqwater, Brisbane.

4.4 Lessons Learned

Refer to recommendations in the Executive Summary (Section 1).

4.5 Implications for the Future

This project demonstrated how palaeoclimate data can be used to supplement instrumental data to get a better understanding into the range of variability that is possible and more realistic estimates for the likelihood of multi-year droughts.

It was clearly demonstrated that the instrumental period is not representative of the full range of past climate variability in SEQ. Further, the hydroclimatic risk profiles and cost-benefit of various water resources planning and adaptation strategies would also be very different if statistics from the 1000-2012 reconstructed rainfall was used instead of (or in addition to) the 1900-2012 instrumental record.

This means that current drought risk estimates, determined using the instrumental record or using stochastic generation based only on statistics from the instrumental record, are at best misleading and probably convey a false sense of security that is not justified given the insights available from palaeoclimate data. Queensland contains the highest proportion of palaeo data allowing a catchment-specific approach to their inclusion in hydroclimatic modelling and water resource management in Queensland.

To transform the way water security planning decisions are made, we need to incorporate more palaeoclimate data into refined and updated hydroclimate risk management plans. This will be the first ever application of such high-resolution proxy data sets to water resource planning in Australia, allowing Queensland to be at forefront of this highly innovation research and directly benefit the agriculture industry. To achieve this we need to:

- Collect and/or develop local palaeoclimate information for Queensland to develop a statistically rigorous time series application-ready online database showing the modes of variability of rainfall, floods and droughts over the last 2000-3000 years (as per that proposed on the Croke et al. ARC Linkage application discussed in Section 2.2.2 with confirmed support from Seqwater and Sunwater and subject to future DCAP funding).

- Use the statistics from the 1000-year rainfall reconstructions to expand on Section 3 to develop new stochastic rainfall simulations that take into account both instrumental and pre-instrumental variability. This should be done with assistance from DSITI (and other relevant industry/government stakeholders who have access to existing stochastic rainfall simulations – and also the models it is used as input for).

- Use the palaeo-informed stochastic rainfall simulations (from the previous point), in the same way existing instrumental-based stochastic simulations are used, to test the ability of current infrastructure, planning or management strategies to deal with the range of hydroclimatic conditions that have occurred in SEQ over the last 1000 years – and where problems are identified propose and test new or improved infrastructure, planning or management strategies so as to improve water security and drought management. This is the focus of a second ARC Linkage application to be submitted August/September 2017 (led by Anthony Kiem at University of Newcastle) and also two ARC Discovery Project applications that were submitted in March (see Appendix D for further details).

- Use climate modelling to determine the physical climate processes associated with the major instrumental and pre-instrumental droughts identified here in order to better understand the causes of multi-year drought (and also the processes associated with bringing a drought to an end). If the physical mechanisms behind the onset, persistence, magnitude, spatial extent and termination of drought can be better understood this will aid seasonal to interannual forecasting of drought and give more confidence in in the future projections of how droughts will change under anthropogenic climate change.

5. Conclusion

This project demonstrated how palaeoclimate data can be used to supplement instrumental data to get a better understanding into the range of variability that is possible and more realistic estimates for the likelihood of multi-year droughts.

It was clearly demonstrated that the instrumental period is not representative of the full range of past climate variability in SEQ. For every statistic considered the full reconstruction periods (1000-2012) gave very different results to that obtained if only the instrumental (1900-2012) period is considered. These differences would result in markedly different outputs from stochastic climate modelling using the two different inputs (i.e. instrumental and reconstructed). Further, the hydroclimatic risk profiles and cost-benefit of various water resources planning and adaptation strategies would also be very different if statistics from the 1000-2012 reconstructed rainfall was used instead of (or in addition to) the 1900-2012 instrumental record.

This means that current drought risk estimates, determined using the instrumental record or using stochastic generation based only on statistics from the instrumental record, are at best misleading and probably convey a false sense of security that is not justified given the insights now available from palaeoclimate data.

6. Financial Statement (Revenue received/Expenses paid/Revenue unspent

As agreed to be supplied after financial reporting for June has been completed.

7. Additional Information

Nil.

8. References

Refer to final report for the full list of references relating to this study.

9. Appendices/Attachments

Final technical report – see attachment 1.

Several journal papers relating to this project are currently “under review” or “in preparation”. We will forward these papers to DSITI and DCAP as soon as they are finalised.