Fingerboards Mineral Sands Project Inquiry and Advisory Committee (IAC)

Expert witness statement by Associate Professor Anthony Kiem (University of Newcastle, Australia)

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Expert witness statement prepared by:
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CONTENTS

I. BACKGROUND INFORMATION

I-A. Expert's name and address

1. Anthony Kiem
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I-B. Expert's qualifications and experience

2. Qualifications:
   - 1999-03: Ph.D. (awarded August 2003), "Multi-temporal Climate Variability in New South Wales, Australia", Discipline of Civil, Surveying and Environmental Engineering, School of Engineering, University of Newcastle, Australia.
   - 1996: Graduate Diploma in Education (Secondary Maths/Science), University of Newcastle, Australia.
   - 1992-95: Bachelor of Mathematics, University of Newcastle, Australia.

3. Relevant experience:
   - 11/2016 – current: Associate Professor – Hydroclimatology, Centre for Water, Climate and Land (CWCL), School of Environmental and Life Sciences, College of Engineering, Science and Environment (CESE), University of Newcastle, Australia.
   - 01/2015 – current: Program Advisor (Education and International Exchange) for Interdisciplinary Centre for River Basin Environment (ICRE), University of Yamanashi, Japan.
   - 10/2014 – current: Visiting Professor (~1 month per year), College of Water Sciences, Beijing Normal University, China.
   - 11/2008 – 11/2016: Hydroclimatologist/Lecturer/Senior Lecturer, School of Environmental and Life Sciences, Faculty of Science, University of Newcastle, Australia.
   - 07/2006 – 11/2008: Hydroclimatologist, Sinclair Knight Merz (SKM), Melbourne, Australia.
   - 11/2003 – 06/2006: Postdoctoral Researcher, Takeuchi-Ishidaira Civil/Environmental Engineering Lab., Uni. of Yamanashi, Japan.
   - 05/2003 – 10/2003: Regional Operations, NSW Environmental Protection Authority, Australia.

I-C. Expert's area of expertise

4. My main area of expertise is understanding the drivers and impacts of hydroclimatic variability and change in the Asia-Pacific region. Of particular interest are:

i. hydrological extremes and how these may change in the future;
ii. the interaction between surface water and groundwater.

5. I have more than 20 years of experience in characterising impacts of hydroclimatic variability and change, seasonal/interannual forecasting, extreme event (e.g. flood, drought, bushfire etc.) risk analysis, hydrological modelling, stochastic modelling, and water resources management.

6. I have also been involved in a wide range of consulting projects where insights into the impacts of hydroclimatic variability and change are used to enable stakeholders from a range of public and private sector organisations to better assess their climate related risk and to develop more informed climate adaptation and mitigation strategies.

I-D. Expert's expertise to make this statement

7. Since 2006 I have been involved in with several projects related to the drivers and impacts of hydroclimatic variability and/or change in Australia, particularly impacts on water resources in eastern Australia (including the Gippsland area where the proposed Fingerboards Mineral Sands Project is located). Through this work I have gained a comprehensive understanding into the current and possible future hydroclimatic conditions in Victoria and therefore am qualified to offer the opinions included in this statement.

8. I have previously given evidence to the Victorian Civil and Administrative Tribunal (VCAT) on similar matters relating to (i) in September 2009, groundwater licences and the Hawkesdale Groundwater Management Area (VCAT reference numbers P549/2008 and P571/2008) and (ii) in August 2010, groundwater licences for a sand mine in Wangaratta (VCAT reference numbers P2505/2008 and P166/2009).

I-E. Instructions that define the scope of this statement

9. On 16th December 2020, I was instructed to:

i. review the technical reports and related documents prepared for the Fingerboards Minerals Sands Project Environment Effects Statement (EES), the proposed Works Approval and the proposed planning scheme amendment that are relevant to your expertise, including the scoping requirements for the EES;
ii. prepare a statement of evidence, relevant to your expertise, on:
    a. the adequacy of the materials and technical reports prepared by the Proponent, noting the IAC has required the Proponent to prepare additional information;
    b. the adequacy of the conclusions expressed in the EES and the other supporting documents;
    c. the adequacy of the proposed mitigation measures and whether additional mitigation measures should be considered;
iii. consider the Council's submission, including the SLR Technical Review and identify any areas of the review to which you disagree.

I-F. Details of any other significant contributors to the statement (if there are any), and their expertise

10. Anthony Kiem was the only contributor to this statement.

II. EVIDENCE

II-A. Relevant science

II-A-1. Impacts of climate variability and change

11. In order to assess and manage climate-related risks for this project it is necessary to consider both the impacts of natural climate change (referred to as **climate variability** in this statement) and the impacts of anthropogenic (human induced) climate change (referred to as **climate change** in this report).This is necessary because historically the main cause of droughts and floods has been climate variability, but from now into the future the role of climate change is projected to increase and add to the impacts of climate variability. Climate-related risk assessments, and associated adaptation strategies, that do not consider the impacts of both climate variability and climate change are counter to objectives to account for climate risks and the potential effects of climate change (e.g. as outlined in the EES Scoping Requirements).

12. Analysis of historical records suggests that the recent Millennium Drought (which occurred from ~1997-2010), while severe, is not unprecedented (Verdon-Kidd and Kiem, 2009) and in fact is not even the worst drought that has occurred or is possible (e.g. Vance et al., 2015; Kiem et al., 2016; Freund et al., 2017). Similarly, multidecadal flood-dominated periods are also possible (e.g. Kiem et al., 2003). I agree with this evidence.

13. For the future, climate model projections (e.g. Climate Change in Australia, (https://www.climatechangeinaustralia.gov.au/en/) indicate that a reduction in rainfall (mostly during the winter half (June to November) of the year) and an increase in temperature is the most likely scenario for Victoria, including the Gippsland area where the proposed Fingerboards Mineral Sands Project is located. This, and the impacts of climate change on other key hydrological variables, suggests an overall reduction in water availability in Victoria. These climate model projections are associated with numerous uncertainties, however, they represent the "best available science" and suggest that a decreasing trend in water availability, superimposed on shorter-term (~ 20 years or less) wetter and drier epochs, is the most likely future scenario (for further details see https://www.water.vic.gov.au/climate-change/climate-and-water-resources-research/the-victorian-water-and-climate-initiative). I agree with these conclusions.

II-A-2. Non-stationarity of rainfall-runoff relationships (and associated changes in interactions between surface water and groundwater)

14. Projected climate changes and associated shifts in precipitation and temperature regimes are expected to influence plant phenology through altered soil water relations (Kiem et al., 2016; Van Loon et al., 2016). This further alters vegetation responses and the hydrological cycle (van Dijk et al., 2013; Van Loon, 2015). In addition, protracted droughts (like the Millennium drought) reduce the connectivity between surface and subsurface water which can further alter hydrological process (Chiew et al., 2014; Deb et al., 2019a). I agree with this evidence.

15. The typical approach, also adopted in the Fingerboards Mineral Sands Project EES, for projecting future hydrological conditions is to use inputs from climate

scenarios in hydrological models that have been calibrated/validated on historical conditions. This means, an implicit assumption is made that the future catchment dynamics will remain as they were in the past (i.e. during the periods used to calibrate the hydrological models). My opinion, based on several recent studies, is that this assumption is not valid. These recent studies (e.g. (Saft et al., 2015; Kim et al., 2015; Tian et al., 2018) demonstrated that this assumption is problematic because catchment characteristics and dynamics are unlikely to remain the same in the future. Catchment characteristics and dynamics are expected to change due to (a) climate-change-induced changes to rainfall, evaporation, and temperature and (b) changes in land use, vegetation, and soil (Saft et al., 2015; Kim et al., 2015; Tian et al., 2018). For instance, during the Millennium drought (~1997-2010), reduced rainfall in southeast Australia was associated with a dramatic and disproportionate reduction in runoff which further led to depletion of reservoirs and hampered agricultural production (Kiem and Verdon-Kidd, 2011; van Dijk et al., 2013). The hydrological modelling community attempted to simulate runoff during the Millennium drought using different hydrological models. In most cases the models performed poorly, with runoff routinely overestimated during the Millennium drought (Chiew et al., 2014; Saft et al., 2016).

16. An seemingly obvious explanation for the reduced observed runoff during the Millennium drought is the decline in rainfall (Verdon-Kidd and Kiem, 2009), however, it has been shown, and is now widely accepted,[1] that only ~52-66% of the reduction in runoff can be explained by the corresponding reduction in rainfall (Potter and Chiew, 2011). Deb et al., (2019a, 2019b) showed that the non-stationarity in rainfall-runoff relationships was due to changes to groundwater table, baseflow, and/or vegetation.

17. The recent work demonstrating the non-stationarity of rainfall-runoff relationships emphasises that in order to obtain realistic hydrological simulations and water balance assessments (especially during droughts) there is a need to carefully consider:

i. catchment characteristics and dynamics;
ii. changes to land use, vegetation, and soil;
iii. changes to surface water and groundwater use (and associated changes to interactions between surface water and groundwater) hydrological extremes and how these may change in the future.

II-B. Adequacy of the materials and technical reports prepared by the Proponent

18. It is unclear if/how the impacts of protracted, multiyear droughts (e.g. like the ~1997-2010 Millennium Drought or the ~1937-1945 World War II drought (Verdon-Kidd and Kiem, 2009)) on surface water (and groundwater) availability have been investigated or taken into account in the EES. The prevailing view is that droughts even worse than the Millennium Drought have occurred in the pre-instrumental past (e.g. Vance et al., 2015; Kiem et al., 2016 Freund et al., 2017). This further emphasises the need to properly consider the impacts of interannual to multidecadal climate variability. My opinion is that the EES Scoping Requirements of *"accounting*

[1] https://www.water.vic.gov.au/climate-change/millennium-drought-report

for climate risks and the potential effects of climate change" are not met because the impacts of protracted, multiyear droughts are not considered.

19. It is unclear if/how the impacts of multiyear (or multidecadal) epochs with a high frequency and clustering of flood events (e.g. like the ~1945-1975 flood dominated period (e.g. Kiem et al., 2003) have been investigated or taken into account in the EES. My opinion is that the EES Scoping Requirements of *"accounting for climate risks and the potential effects of climate change*" are not met because the impacts of multiyear (or multidecadal) epochs with a high frequency and clustering of flood events are not considered.

20. Non-stationarity of rainfall-runoff relationships, and associated changes in interactions between surface water and groundwater have not been taken into account. This is a critical issue given the amount of surface water and groundwater required for this project. As explained in Section II-A-2, there is increasing evidence of reduced runoff per unit rainfall in most catchments across Victoria and this is related to changes (natural and/or caused by human activities) to the groundwater table, baseflow, and/or vegetation (Saft et al., 2015; Fowler et al., 2016; Deb et al., 2019a, 2019b). The impacts of changes to the groundwater table, baseflow, and/or vegetation on rainfall-runoff relationships are non-linear and associated with lags (from several months to several years). This project will have some impact on groundwater table, baseflow and vegetation so it needs to be determined how these impacts could affect rainfall-runoff relationships (and surface water availability) in the project area. My opinion is that the EES Scoping Requirements of *"accounting for climate risks and the potential effects of climate change*" are not met because non-stationarity of rainfall-runoff relationships has not been considered.

21. It is not clear that the projected impacts of anthropogenic climate change, and associated uncertainties, have been adequately accounted for in the water balance assessments, surface water modelling, or groundwater modelling. Median (50^{th} percentile) climate change projections for the year 2040 were adopted but this ignores some of the higher impact climate projections that are equally plausible. For example, the annual rainfall change used in the EES was 2.3% decrease by 2040 but data from Climate Change in Australia (https://www.climatechangeinaustralia.gov.au/en/) shows that anything from ~15% decrease to a 5% increase is plausible by 2040. While the 2.3% decrease by 2040 in annual rainfall used by the EES is within the range of what is plausible by 2040, decreases in annual rainfall up to ~15% (or increases of up to ~5%) are equally plausible. Justification for use of the median (50^{th} percentile) 2.3% decrease in annual rainfall as the future climate change projection is required. Sensitivity of the results and conclusions to this decision also needs to be assessed (i.e. how different are the water balance assessments, surface water modelling, and groundwater modelling if 10-15% decrease in annual rainfall is used as the climate change projection?). My opinion is that the precautionary principle is not followed if just the median projected change is used to assess climate change impacts.

II-C. Adequacy of the conclusions expressed in the EES and the other supporting documents

22. The following surface water related conclusions expressed in the EES (copied in *italics* below) are not adequate:

i. From Section 13.1.3 in the EES: *The project will require water for activities such as ore processing, dust suppression, rehabilitation, and wash-down, as well as for domestic uses. During operations, water requirements are likely to be approximately 3 gigalitres per year. Water for the project will be sourced from the Mitchell River.*
   a. As pointed out by many submissions it is not clear that 3 gigalitres/year of water will be available, especially during drought. If 3 gigalitres/year is not able to be sourced from the Mitchell River then it is not clear what the contingency plan is to source the water required for the project's activities.
   b. It has also not been adequately explained if/how the allocation of 3 gigalitres/year of water to the project will compete with other water users (e.g. agriculture) and whether this might prevent the expansion or affect the viability of agricultural industries.
   c. Further analysis is also required to demonstrate that allocating 3 gigalitres/year of water, assuming it is available, to this project is the most beneficial use of this water (in terms of economic, environmental, and social/community benefits).
   d. It is unclear why this project should be given priority access to 3 gigalitres/year of water.

ii. From Section 13.1.3 in the EES: *Surface water extraction for the project is subject to the granting of a winterfill licence by the regulatory authority. Extraction would occur only in line with the conditions, timings, and limits detailed in the licence. Extraction will be restricted to days between July and October when flows exceed 1,400 million litres/day. The project is not expected to impact on the rate at which the winterfill threshold is reached. Analysis of flow data for the past 10 years identified only 16 days over the 10-year period where the additional extraction for the project (24 million litres/day or 3 gigalitres/year) would have led to restrictions. Surface water availability for winterfill licence holders will not be significantly impacted by the project.*
   a. Submission 291 from Southern Rural Water confirms that access to this surface water is not guaranteed. Point 5 in Submission 38 from Southern Rural Water provides further information and indicates significant variability in the number of days per year that extraction would be allowed (i.e. days where flow exceeds 1,400 million litres/day). It should also be noted that the period analysed (both in the Proponents EES and Submission 38 from Southern Rural Water) does not cover the recent, protracted drought that occurred across most of southeast Australia from ~1997-2010 (i.e. the Millennium Drought). Analysis should be conducted to determine number of days per year where flow exceeds 1,400 million litres/day during a protracted drought and viability of the surface water extraction needed for the project should be re-evaluated based on that information.

iii. From Section 13.1.3 in the EES: *Extraction of groundwater from the Latrobe Group Aquifer would be in line with a licence issued by Southern Rural Water. A groundwater licence application would be subject to an assessment of the potential impacts of the groundwater extraction on the existing and potential uses of the resource. Groundwater mounding and* *drawdown of groundwater levels as a result of project activities are not expected to affect the availability of groundwater to licenced users.*

a. Point 1 in Submission 38 from Southern Rural Water indicates that the groundwater licence mentioned might not be approved unless a trade can be organised (and approved) to access groundwater from an existing licence holder. It is not clear what will happen if the groundwater licence is not approved and extraction of groundwater from the Latrobe Group Aquifer is not allowed.

iv. From Section 13.1.3 in the EES: *The project will be managed to maximise the efficiency of water use, prevent offsite release of stormwater from mining areas, maintain environmental flows in watercourses through clean water diversions. Mitigation measures will be implemented in accordance with the EMF to avoid potential impacts to beneficial uses of surface water and groundwater resources. Potentially contaminated stormwater will be captured in water management dams for reuse in the process water system for the mine.*

a. Capturing stormwater in water management dams will alter the hydrology of the location (including recharge of surface water and groundwater systems). This will alter rainfall-runoff relationships and could exacerbate the reduction in runoff per unit rainfall already being experienced (especially during droughts). This has not been considered in the EES.

b. The stormwater captured by the water management dams will potentially be contaminated. It is not clear if/how the EES assesses or manages the risk of failure of the water management dams (e.g. during multiyear (or multidecadal) epochs with a high frequency and clustering of extreme rainfall events). Further analysis is required to demonstrate that the water management dams are robust even under the most extreme rainfall conditions (accounting for the impacts of both climate variability and climate change on extreme rainfall). Details should also be provided about the contingency plan (and clean up) if contaminated stormwater is released from the water management dams.

II-D. Adequacy of the proposed mitigation measures and whether additional mitigation measures should be considered

23. SW01 (from the Mitigation Register in Attachment H) states that "*Surface water will be extracted from the Mitchell River in line with the conditions, timings, and limits detailed in any licence issued by Southern Rural Water".* As previously discussed, it is unlikely that the required amount of surface water will be available (especially during droughts). Additional mitigation measures should be given which detail what happens if/when the required water is not available from the Mitchell River.

24. SW33 (from the Mitigation Register in Attachment H) states that *"If during successive storm events, water management dams are required to be drawn down at a rate greater than can be achieved by the process water demand, mine contact water will be treated at a rate of 24 ML/day prior to discharge to the freshwater storage dam. Mine contact water will be treated to meet licence requirements prior to discharge offsite".* Analysis should be conducted to quantify the likelihood of this

situation occurring (accounting for the impacts of both climate variability and climate change on extreme rainfall). Analysis should also be conducted to confirm that space would be available in the freshwater storage dam during situations where there are successive storm events.

25. SW37 (from the Mitigation Register in Attachment H) states that *“Natural surface water drainage courses will be re-routed to avoid post-mining landforms, where practicable”.* Further details should be provided to clarify what is meant by “where practicable”. Similar should be done for other mitigation measures that include “where practicable”.

26. SW38 and SW39 involves changing the catchment characteristics. This will alter rainfall-runoff relationships and could exacerbate the reduction in runoff per unit rainfall already being experienced (especially during droughts). Changes to catchment characteristics such as that proposed in SW38 and SW39 need to be modelled (accounting for the impacts of both climate variability and climate change) so that the impacts of the changes can be quantified and effectively managed.

III. SUMMARY

27. It is unclear if/how the impacts of protracted, multiyear droughts (e.g. like the ~1997-2010 Millennium Drought or the ~1937-1945 World War II drought) on surface water (and groundwater) availability have been investigated or taken into account in the EES. The prevailing view is that droughts even worse than the Millennium Drought have occurred in the pre-instrumental past. This further emphasises the need to properly consider the impacts of interannual to multidecadal climate variability. My opinion is that the EES Scoping Requirements of "accounting for climate risks and the potential effects of climate change" are not met because the impacts of protracted, multiyear droughts are not considered.

28. It is unclear if/how the impacts of multiyear (or multidecadal) epochs with a high frequency and clustering of flood events have been investigated or taken into account in the EES. My opinion is that the EES Scoping Requirements of *“accounting for climate risks and the potential effects of climate change*” are not met because the impacts of multiyear (or multidecadal) epochs with a high frequency and clustering of flood events are not considered.

29. An assumption is made in the hydrological modelling and water balance assessment that the future catchment dynamics will remain as they were in the past (i.e. during the periods used to calibrate the hydrological models). My opinion, based on several recent studies, is that this assumption is not valid. My opinion is that the EES Scoping Requirements of “accounting for climate risks and the potential effects of climate change” are not met because non-stationarity of rainfall-runoff relationships has not been considered.

30. While the 2.3% decrease by 2040 in annual rainfall used by the EES is within the range of what is plausible by 2040, decreases in annual rainfall up to ~15% (or increases of up to ~5%) are equally plausible. Justification for use of the median (50^{th} percentile) 2.3% decrease in annual rainfall as the future climate change projection is required. Sensitivity of the results and conclusions to this decision also needs to be assessed (i.e. how different are the water balance assessments, surface water modelling, and groundwater modelling if 10-15% decrease in annual rainfall is used as the climate change projection?). My opinion is that the precautionary principle is not followed if just the median projected change is used to assess climate change impacts.

31. The project proposes to capture stormwater in water management dams. This will alter the hydrology of the location (including recharge of surface water and groundwater systems). This will alter rainfall-runoff relationships and could exacerbate the reduction in runoff per unit rainfall already being experienced (especially during droughts). This has not been considered in the EES.

32. The stormwater captured by the water management dams will potentially be contaminated. It is not clear if/how the EES assesses or manages the risk of failure of the water management dams (e.g. during multiyear (or multidecadal) epochs with a high frequency and clustering of extreme rainfall events). Further analysis is required to demonstrate that the water management dams are robust even under the most extreme rainfall conditions (accounting for the impacts of both climate variability and climate change on extreme rainfall). Further details should also be provided

about the contingency plan (and clean up) if contaminated stormwater is released from the water management dams.

IV. DECLARATION

33. I have made all the inquiries that I believe are desirable and appropriate and no matters of significance which I regard as relevant have to my knowledge been withheld from the Panel.

34. I disclose that when preparing this statement, it was not possible for me to conduct a site visit because of COVID-19 related travel restrictions put in place by the New South Wales and Victorian governments (and also by my employer, the University of Newcastle). However, I confirm that I have been to this location before and am familiar with the hydroclimatic and geographical characteristics of the location that are relevant to my statement.

Signed ……… ………………………………

Dated ………1 February 2021……………………..

V. REFERENCES

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VI. CURRICULUM VITAE FOR ANTHONY KIEM

Anthony Kiem

ASSOCIATE PROFESSOR – HYDROCLIMATOLOGY
CENTRE FOR WATER, CLIMATE AND LAND (CWCL)
UNIVERSITY OF NEWCASTLE, AUSTRALIA
20 years professional experience.
Australian citizen, based in Newcastle.
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QUALIFICATIONS

- 1999 – 03 Ph.D. (awarded August 2003), "Multi-temporal Climate Variability in New South Wales, Australia", Discipline of Civil/Environmental Engineering, University of Newcastle, Australia
- 1996 Graduate Diploma in Education (Secondary Maths/Science), University of Newcastle, Australia
- 1992 – 95 Bachelor of Mathematics, University of Newcastle, Australia

RECENT AWARDS/HONORS

- 11/2020: University of Newcastle Faculty of Science Award for Research Supervision Excellence.
- 12/2016: Institution of Engineers Australia, 2016 GN Alexander Medal for the best paper in hydrology and/or water resources published between Jun 2015 and Dec 2016. (Ho, Kiem and Verdon-Kidd (2015): Droughts and pluvials in the Murray-Darling Basin over the past two and a half millennia).
- 03/2015: 2014 Outstanding Reviewer for Journal of Hydrologic Engineering (American Society of Civil Engineers).
- 12/2013: University of Newcastle Faculty of Science Award for Academic Team of the Year (for Geographic Information Systems (GIS) teaching) - Anthony Kiem was Team Leader and Course Coordinator.
- 06/2011: Institution of Engineers Australia, 2011 GN Alexander Medal for the best paper in hydrology and/or water resources published between Dec 2009 and Jun 2011. (Verdon-Kidd, D.C. and Kiem, A.S. (2009): Relationship between large-scale climate drivers and Victorian rainfall variability – why was the last decade so dry?).

SUMMARY OF EXPERTISE

Anthony's focus is on understanding the drivers and impacts of climate variability and change in the Asia-Pacific region. Of particular interest are hydrological extremes and how these may change in the future. Other areas of expertise include:

- Extreme event (e.g. flood, drought, bushfire etc.) risk analysis.
- Water resources management.
- Climate change impact, risk and vulnerability assessment.
- Seasonal/interannual hydroclimatic forecasting.
- Adaptation strategy, planning, monitoring and evaluation.
- Hydrological modelling.
- Stochastic modelling.

PROJECT EXPERIENCE

Anthony has been involved in a wide range of projects where stakeholders from a range of public and private sector organisations assess their climate related risks and develop more informed climate adaptation and mitigation strategies. Some examples of recent relevant projects that Anthony has led include:

- **Flooding in Australia – are we properly prepared for how bad it can get?** Client: Australian Research Council (ARC). The cost and impact of flooding is high yet current and future flood risk is poorly understood. This project tackles this problem by implementing new historical data to show how floods have varied over the past 2000 years. More accurate estimates of how bad flooding can get will enable development of novel adaptation strategies (e.g. infrastructure, planning policy) that reduce the costs of floods and are optimal and robust under a range of plausible futures.
- **Review and application of hydrodynamic and water quality models for the Long Xuyen Quadrangle (Vietnam).** Client: The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)GmbH. The two provinces of An Giang and Kien Giang, together with the Ministry of Agriculture and Rural Development (MARD) and the Ministry of Natural Resources and Environment (MONRE) and through the support of GIZ, developed a Cross Boarder Water Management Agreement for the Long Xuyen Quadrangle. A priority activity identified within the water management agreement is the development of hydrodynamic and water quality models and the assessment of climate change impacts. I am responsible for data collection and analysis, development of the hydrological models and provision of high resolution climate change information for the Long Xuyen Quadrangle.
- **Water security in the Campaspe basin, Victoria.** Client: Australian Department of Climate Change (DCC). Anthony was principal investigator on this project which assessed changes in water security in the Campaspe River catchment in response to the impacts of climate variability and human-induced climate change. Surface water flow regime and water security in the Campaspe basin was found to vary with phases of the Interdecadal Pacific Oscillation (IPO). Best-case projections for climate change in 2030 are for similar to historical water supply conditions. The worst case for climate change would see drastic reductions in supply reliability and the need for far reaching adaptive measures.
- **Learning from the past – incorporating palaeoclimate data into water security planning and decision-making.** Client: Queensland Department of Environment and Science (DES) and South East Queensland Water (Seqwater). This project demonstrated how palaeoclimate data can be used to supplement instrumental data to get 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 South East Queensland. This means that current drought risk estimates are at best misleading and probably convey a false sense of security that is not justified given the insights now available from palaeoclimate data.
- **Madhya Pradesh (India) Irrigation Efficiency Improvement Project (MPIEIP) – Climate Risk and Vulnerability Assessment (CRVA).** Client: Asian Development Bank (ADB). ADB is supporting the development of ~125,000 hectares of new, highly efficient irrigation networks under the ~$560

million Kundaliya Irrigation Project (KIP) in the northwestern part of Madhya Pradesh. This CRVA provided understanding and quantification of the climate risks and vulnerabilities facing the KIP and also assessed the costs and benefits of climate risk adaptation options.

- **Multisite rainfall and evaporation data generation for the Hunter Water Infrastructure Project.** Client: NSW Department of Primary Industries - Water. This study stochastically generated multiple replicates of 10,000 year daily rainfall and evaporation time series at multiple sites across the Hunter Water Infrastructure Project area. Key statistical properties important for hydrological response and water planning outcomes were realistically simulated. This included: number and distribution of rain days; rainfall depth; intensity, frequency and duration of extreme rainfall events; severity and duration of below average rainfall; variability over interannual to multidecadal time scales; and multi-site rainfall and evaporation dependency.
- **Analysis of trends, variation, frequency and change detection in hydroclimatic variables for the Lower Mekong Basin.** Client: Mekong River Commission (MRC). This project analysed historical trends, variability and changes in historical hydroclimatic conditions (including storms and extreme rainfall) in the Lower Mekong Basin (LMB).
- **Climate Risk and Vulnerability Assessment (CRVA) for power transmission improvement project in Myanmar.** Client: Asian Development Bank (ADB). ADB funded the Myanmar power transmission improvement project (PTIP) to complete the critically important 230 kilovolt (kV) transmission ring supplying electricity for Yangon and to ensure reliable electricity supply to support sustainable economic development for Myanmar. This CRVA provided better understanding and quantification of the climate risks and vulnerabilities facing the PTIP and also assessed the costs and benefits of possible climate risk adaptation or mitigation options.
- **Developing criteria, methodology, and conducting the selection of suitable emission scenarios, climate models, and climate change impact scenarios for the Lower Mekong Basin.** Client: Mekong River Commission (MRC). This project developed appropriate regional climate change scenarios to be used to provide information to assess potential impacts of climate change on natural and socio-economic systems in the Lower Mekong Basin and to provide information to support climate change adaptation planning in the Mekong River Commission (MRC) member countries (Cambodia, Lao PDR, Thailand, and Vietnam).
- **Robust optimization of urban drought security for an uncertain climate.** Client: National Climate Change Adaptation Research Facility (NCCARF). Decision makers need to deal with significant uncertainty about future climate and population. In particular the accuracy of climate model projections is limited by fundamental irreducible uncertainties. It is unwise to unduly rely on projections made by climate models and prudent to favour solutions that are robust across a range of possible climate futures. This study presents and demonstrates a methodology that addresses the problem of finding “good” solutions for urban bulk water systems in the presence of deep uncertainty about future climate. Multi-objective optimisation is used to efficiently search through potentially trillions of solutions to identify a set of “good” solutions that optimally trade-off cost against robustness over a range of plausible future scenarios.