In the matter of:	Clauses 6 and 8 of Schedule 1 – Resource Management Act 1991 – Submissions on publicly notified plan change and variation – Proposed Plan Change 1 and Variation 1 to Waikato Regional Plan – Waikato and Waipa River Catchments
And:	**Wairakei Pastoral Ltd** Submitter
And:	**Waikato Regional Council** Local Authority

Statement of evidence of Phillip William Jordan

Block 1 Hearing Topics

Dated: 15 February 2019

SUMMARY AND CONCLUSIONS

1. My evidence for the Block 1 Hearing Topics focuses primarily on the science that underpins PC1 (Topic B3) based on my own expertise - and my review of the Section 32 Evaluation Report, the relevant background reports referenced in the bibliography to that report, and the matters addressed in the Section 42A Report. I have some concerns about the underlying science (as noted below) and illustrate how they could be resolved by providing an overview of relevant aspects of the science modelling commissioned by WPL (the **RSDT**). I will cover this in detail in my later evidence for the Block 2 Hearing Topics (Topics C1 and C4).

2. Point 2 of Paragraph 276 of the Section 42A Report states that, "Officers consider the science and economic analysis and modelling to be both comprehensive and adequate to enable the RMA requirements in s32 to be fulfilled." However, I disagree with this statement as there are aspects of the hydrological and water quality modelling that are not adequate in accurately capturing the hydrological and water quality response of the catchment. In my view, these deficiencies in modelling contaminants undermine the reliability of conclusions made using the modelling to support the argument that PC1 fulfils the requirements of the RMA.

3. Contaminant loads for Scenario 1 at locations along the Waikato River (that underpin PC1) were derived from modelling undertaken in CLUES (Semadeni-Davies et al., 2015 & 2016). Within each sub-catchment, the CLUES model then reduced the mean annual load delivered using a sub-catchment attenuation factor. Loads delivered from each sub-catchment, after sub-catchment level attenuation, were then accumulated to downstream reaches, in accordance with the topology of the sub-catchments and stream reaches.

4. CLUES is a steady state model. A key assumption of the model is that the statistics for water quality attributes produced by the model are produced in response to attributes describing the catchment state over a contemporaneous period. CLUES cannot explicitly represent the dynamics of a catchment that is changing over time, for example due to changes in land use, delays induced by processes that occur in catchments, multi-year or multi-decadal climate variability or climate change. Semadeni-Davies et al. (2015, 2016) modified some of the parameters of the CLUES model, in an attempt to compensate for its steady state nature, notably with regard to assumed delays in transport of nitrogen load via groundwater flow pathways.

5. The modelling undertaken by Semadeni-Davies et al. (2015 & 2016) was calibrated to statistics computed from water quality monitoring data collected over the period 2010-14. The parameters of the CLUES model were calibrated, to achieve a calibration to various statistics calculated from the monitored water quality and flow data recorded within the catchment. The calibration process tuned all of the

parameters of the CLUES models, including the unattenuated loading rates associated with each of the six land uses (described in my evidence below), the modifying factor for poor and moderately drained soils, and the sub-catchment attenuation factors for each sub-catchment.

6. Semadeni-Davies et al. (2016) adjusts for the shortcomings of CLUES as a steady-state model using a single measure, by modifying the "apparent" sub-catchment attenuation factors that were adopted for modelling the scenarios (including the adopted Scenario 1) to represent "ultimate" sub-catchment attenuation factors. Where changes were made between the "adjusted" and "ultimate" attenuation factors, the justification for these changes is limited to the short descriptions in the "load to come" column of Table 3-2 and the discussion on pp 23 and 24 of Semadeni-Davies et al. (2016).

7. The CLUES modelling assumes that there is significant TN "load to come", particularly in the Upper Waikato, sub-catchment numbers 74, 73 and 66 of PC1, which correspond to sub-catchment numbers 1, 2 and 3 of Semadeni-Davies et al. (2016). The assumptions about TN attenuation, in turn, influence the projected changes in land use that were produced for each of the scenarios to achieve the objectives.

8. The CLUES modelling is heavily dependent upon the assumptions made about current and future attenuation of TN in the groundwater. The difference between these two rates of attenuation determines the load to come of TN in the groundwater. The estimates of apparent (or current) attenuation are derived via the fitting process of the CLUES model to observed annual loads. There is some uncertainty about the apparent rates of TN attenuation.

9. There would appear to be much more uncertainty about the assumed ultimate, or future, attenuation coefficients, as these were apparently selected via an "expert panel" process. There is little in the way of further objective evidence, in the technical reports, to support the attenuation coefficients that were adopted for TN for the ultimate case.

10. Calculation of statistics across a five-year analysis period (2010-14) would, in general, result in smoothing out seasonal, i.e. within year, variations due to, for example, climatic variation. However, I do not support a generalisation that the five-year period selected to establish the current state statistics, 2010-14, would produce an unbiased statistical assessment of the current state for water quality. This is because (a) some processes, such as generation and transport of dissolved N via groundwater flow pathways occur over periods that may be longer than five years, and (b) the catchment responds to trends and variations in climate that are subject to periods that are longer than five years.

11. The sub-catchment delineation adopted for PC1 appears to have mainly been determined by the method of data analysis and modelling

approach adopted to support the CSG, instead of fundamental differences in hydrological or water quality response between sub-catchments. The sub-catchments defined in the plan in Table 3.11-2 were determined by these limitations in the modelling approach and method of data analysis.

12. In my experience, it is possible to develop an alternative modelling framework that would allow water quality outcomes to be predicted, with some level of confidence, at locations other than those with existing monitoring data. An alternative model would also be a dynamic model, which could overcome the concerns that I have expressed about the shortcomings of CLUES as a steady state model. An alternative model could therefore produce defensible outcomes for PC1 to support an alternative arrangement of sub-catchments to those set out in Table 3.11-2 of PC1 (e.g. subdividing Sub-catchment 66).

13. In summary, I have concerns about the underlying science and modelling used in preparing PC1, including:

    a) Aspects of the hydrological and water quality modelling that are not adequate in accurately capturing the hydrological and water quality response of the catchment;

    b) The modelling approach adopted, including the use of CLUES, includes considerable uncertainty;

    c) The use of the five-year period (2010-2014) to calculate current state statistics is not supported as it is likely to have produced a biased result, including an under-estimation of contaminant concentrations and loads for the current state of water quality and also for all of the scenarios, including that for 1863 which means that the 80-year water quality objectives for at least some of the constituents, at some locations, may not be met;

    d) Deficiencies in modelling contaminants undermine the reliability of the conclusions made;

    e) The sub-catchment delineation was determined by limitations in the modelling approach and method of analysis adopted.

14. An alternative modelling framework is available that would allow land use change and water quality outcomes to be predicted with some level of confidence and at locations other than those with existing monitoring data. This would allow for an alternative arrangement of sub-catchments. The RDST, developed for WPL, is a viable alternative model.

EVIDENCE

Block 1 Hearing Topics

1. My name is **Phillip William Jordan**. I have the qualifications and experience recorded in my curriculum vitae attached to this statement of evidence as **Appendix 1**. I have twenty-two years of experience in hydrology and water resources engineering. Key aspects of my recent expert experience relevant to this Hearing includes:

    a. I was the Product Project Leader for the development of eWater's Source Catchments modelling package and have extensive experience in applying Source to water quality modelling in New Zealand and Australia.

    b. I developed catchment models and provided expert witness statements for the Tukituki catchment Board of Inquiry and the Selwyn Waihora plan change assessments.

    c. I worked as an independent expert witness for the Queensland Floods Commission of Inquiry in 2011.

    d. I was the lead author of two chapters of the 2016 update of Australian Rainfall and Runoff, the Australian guideline on flood hydrology.

    e. I have been an author or co-author on eight papers that have been published in peer reviewed Australian and International journals. I have been a co-author or presenter of more than 50 conference papers

2. I have been engaged to prepare this evidence in support of the submissions and further submissions made by Wairakei Pastoral Ltd (**WPL**) on the Proposed Waikato Regional Plan Change 1 (**PC1**) and Variation 1 to Proposed Waikato Regional Plan Change 1 – Waikato and Waipa River Catchments (**Var1**).

3. Relevant to my qualifications and experience, my evidence focuses on developing the surface water runoff and quality component of an alternative, sub-catchment level model, which WPL is putting forward as a viable and sufficiently accurate alternative approach for assessing the impacts of land management and land use in the Ruahuwai sub-catchments (Waikato River catchment, upstream of Lake Ohakuri) (Ruahuwai Decision Support Tool (**RDST**)). The surface water and water quality constituent generation component of the model was developed in the eWater Source modelling framework. I have been involved in calibrating the surface water runoff, recharge to groundwater and nutrient, sediment and E. coli generation components of the model. I have also been involved in developing and reviewing the application of the proposed sub-catchment level model

to assess prospective future land use and land management scenarios for the Ruahuwai sub-catchments.

4. My evidence has been prepared in accordance with the Code of Conduct for expert witnesses as set out in Section 7 of the Environment Court of New Zealand Practice Note 2014.

Scope of my evidence

5. The scope of my evidence is as follows:

   a. Review of the Collaborative Stakeholder Group (**CSG**) technical reports and Section 32 Evaluation Report and related documents.

   b. Assessment of reliability of the modelling supporting PC1.

   c. Development of the RDST by WPL.

   d. Conclusions.

Review of CSG technical reports and Section 32 Evaluation Report

6. Healthy Rivers: Plan for Change/Wai Ora: He Rautaki Whakapaipai (**HRWO**) was approved by Waikato Regional Council (**WRC**) for public notification on 22 October 2016.

7. WRC has expended considerable and useful effort on the process of PC1. PC1 was supported by a number of technical reports. I have reviewed the information that was presented in the following technical reports, which were referenced by the CSG and WRC in support of PC1:

   a. Hudson, N., S. Elliott, R. Robinson and S. Wadhwa (2015), Review of historical land use and nitrogen leaching: Waikato and Waipa catchments, Report No. HR/TLG/2015-2016/1.4, Released 23 November 2015.

   b. Semadeni-Davies, A., S. Elliott and S. Yalden (2016), Modelling Nutrient Loads in the Waikato and Waipa River Catchments, Report No. HR/TLG/2016-2017/2.2A, Released 21 October 2016.

   c. Hughes, A. (2015), Waikato River suspended sediment: loads, sources & sinks, Report No. HR/TLG/2015-2016/2.4, Released 8 December 2015.

d. Betts, H. (2015), Extracting NZeem-estimated sediment yield data for Agribase farm boundaries within HRWO catchments, Report No. HR/TLG/2015-2016/2.5, Released 1 December 2015.

e. Semadeni-Davies, A., S. Elliott and S. Yalden (2015), Modelling E. coli in the Waikato and Waipa River Catchments, Report No. HR/TLG/2015-2016/2.6, Released 11 November 2015.

f. Wadhwa, N. and S. Elliott (2015), Refined classification of land characteristics to assist economic modelling, Report No. HR/TLG/2015-2016/2.7, Released 1 December 2015.

g. Verburg, P. (2016), Nutrient limitation of algal biomass in the Waikato River, Report No. HR/TLG/2015-2016/3.4, Released 1 June 2016.

h. Doole, G., N. Hudson and S. Elliott (2016), Prediction of water quality within the Waikato and Waipa River catchments in 1863, Report No. HR/TLG/2016-2017/4.3, Released 2 August 2016.

i. Keenan, B. (2016), Municipal and industrial water values in the Waikato River catchment: Memo to TLG on Point Sources, Report No. HR/TLG/2015-2016/4.9, Released 9 October 2016.

j. Robak, A., J. Crawford and J. Vessey (2015), Municipal & Industrial Water Values in the Waikato River Catchment, Report No. HR/TLG/2016-2017/4.10, Released 9 October 2015.

k. Wedderburn, L. and A. Coffin (2016), Baseline Report, Report No. HR/TLG/2015-2016/6.1, Released 1 March 2016.

l. Moriarty, E. and B. Gilpin (2015), Sources of Faecal pollution in Selected Waikato Rivers - July 2015, Report No. HR/TLG/2015-2016/7.3, Released 23 November 2015.

Assessment of reliability of the modelling supporting PC1

8. Point 2 of Paragraph 276 of the Section 42A Report states that, “Officers consider the science and economic analysis and modelling to be both comprehensive and adequate to enable the RMA requirements in s32 to be fulfilled.” As I will set out in the remainder of my evidence, there are aspects of the hydrological and water quality modelling that are not adequate in accurately capturing the hydrological and water quality response of the Waikato River catchment. In my view, these deficiencies in modelling contaminants therefore undermine the reliability of conclusions made using the modelling to support the argument that PC1 fulfils the requirements of the RMA.

9. Contaminant loads for Scenario 1 at locations along the Waikato River were derived from modelling undertaken in CLUES (Semadeni-Davies et al., 2015 & 2016). The model structure for CLUES is explained in section 2 of Semadeni-Davies et al. (2016), where the unattenuated load is first derived for each sub-catchment using equation (3) as a function of:

   a. The estimated proportion of each sub-catchment assigned to each of six land uses: dairy, intensive sheep and beef grazing, hill country sheep and beef grazing, urban, forest (combining exotic forest, native forest and scrub) and all other land uses;

   b. Coefficients assigned to each of the above six land uses, which could be conceptualised as an unattenuated load for the particular constituent per unit area for the given land use;

   c. The estimated proportion of the sub-catchment that has poor to moderate drainage;

   d. A coefficient modifying the overall export of the particular sub-catchment for the proportion of the sub-catchment with poor to moderate drainage.

10. Within each sub-catchment, the CLUES model then reduced the mean annual load delivered using a sub-catchment attenuation factor. Loads delivered from each sub-catchment, after sub-catchment level attenuation, were then accumulated to downstream reaches, in accordance with the topology of the sub-catchments and stream reaches, as shown in Figure 2-1 of Semadeni-Davies et al. (2016).

11. Further in-stream attenuation to account for removal of constituent loads in lakes and reservoirs was also applied to the accumulated loads within eight of the stream reaches, as listed in Table 3-1 of Semadeni-Davies et al. (2016).

12. CLUES is a steady state model (Parliamentary Commissioner for the Environment, *Overseer and regulatory insight: Models uncertainty and cleaning up our waterways*, December 2018, p 106). A key assumption of the model is that the statistics for water quality attributes produced by the model are produced in response to attributes describing the catchment state over a contemporaneous period. CLUES cannot explicitly represent the dynamics of a catchment that is changing over time, due for example to changes in land use, delays induced by processes that occur in catchments, multi-year or multi-decadal climate variability or climate change. Semadeni-Davies et al. (2015, 2016) modified some of the parameters of the CLUES model, in an attempt to compensate for its steady state nature, notably with regard to assumed delays in transport of Nitrogen (**N**) load via groundwater flow pathways. Based upon my understanding of the CLUES modelling, as presented in Semadeni-

Davies et al. (2015, 2016), no modifications were made for any other water quality constituents to accommodate for the steady-state nature of the CLUES modelling framework.

13. The modelling undertaken by Semadeni-Davies et al. (2015 & 2016) was calibrated to statistics computed from water quality monitoring data collected over the period 2010-14. The parameters of the CLUES model were calibrated, to achieve a calibration to various statistics calculated from the monitored water quality and flow data recorded within the catchment. The calibration process tuned all of the parameters of the CLUES models, including the unattenuated loading rates associated with each of the six land uses (noted above), the modifying factor for poor and moderately drained soils and the sub-catchment attenuation factors for each sub-catchment.

14. Paragraph 586 of the Section 42A Report argues that the 5-year averaging period selected, from 2010-14, “to summarise the monthly monitoring results in Table 3.11-1 of PC1 means that any short term variability in water quality, including seasonal variability, will be accounted for by the substantially longer averaging period (i.e. five years)”. I provide conditional support for this statement, in that calculation of statistics across a five-year analysis period (2010-14) would, in general, result in smoothing out seasonal, i.e. within year, variations due to within year climatic variation. However, I do not support the more general statement that the five-year period selected to establish the current state statistics, 2010-14, produced an unbiased statistical assessment of the current state for water quality. This is because (a) some processes, such as generation and transport of dissolved N via groundwater flow pathways in some parts of the catchments may occur over periods that may be longer than five years, and (b) the catchment responds to trends and variations in climate that are subject to cycles that are longer than five years.

15. The calendar years comprising 2010-14 was a particularly dry period in the Upper Waikato, when compared with a longer-term analysis of recent climate. Dr Neale’s evidence (paragraph 63) notes that the mean annual rainfall for the Taupo Automatic Weather Station for 1991 to 2014 (inclusive) was 953 mm. The mean annual rainfall at the same site for 2010-14 (inclusive) was 862 mm, which was 10% lower than the longer term mean. Dr Neale also notes that the 2010-14 period contained the two driest years since 1991: 2013 (645 mm) and 2014 (606 mm) (paragraph 64). Dr Neale (paragraphs 65-67 and Figure 1) demonstrates that for the Pueto Stream, as an example, the drier than average years over 2010-14 result in median Total Phosphorus (**TP**) in all years between 1993 and 2015, with the exception of 2013 and 2014, falling above the median TP for 2010-14, which defined the “current state” used in PC1. Dr Neale therefore states that, “the use of monitoring data from this five-year period without reference to, or accounting for the unusually dry conditions may lead to biased assessments of the current state of the river. This

bias is likely to lead to an under-estimation of the current state of water quality in the catchment."

16. To emphasise this point, from Mr Williamson's evidence, it is noted that much of the Nitrate and Total Nitrogen (**TN**) load delivered to the Waikato River would have been dissolved in young, shallow groundwater that had little time to denitrify. The drier than average period of 2010-14 is likely to have seen lower volumes of recharge from the upper catchment when compared with a longer period. Drawing together conclusions from the evidence of Mr Williamson and Dr Cresswell, the drier than average period of 2010-14 is likely to have caused lower Nitrate and TN concentrations to be recorded in the monitoring data over 2010-14 due to reduced soil losses and enhanced catchment-wide biological N uptake than would have been the case over a period with rainfall more representative of current average conditions.

17. Dr Neale (paragraph 71) recommends that, "current state assessments are re-assessed with reference to rainfall variability to reduce any bias that may be introduced by unusually dry or wet periods." I agree with this recommendation as explained below.

18. On the basis of Dr Neale's evidence, if we accept that the statistics of the constituents derived from monitoring data collected over the period 2010-14 underestimate the true current state of water quality statistics over a longer current period, then this will bias the calibrated parameter values for the CLUES model.

19. For example, if the concentration and load statistics derived from 2010-14 monitoring data are low-biased estimates of the concentrations and loads for the current state, then as a compensating measure the CLUES model will have estimated generation rates for some or all land uses and/or "apparent" sub-catchment attenuation factors that will have lower values than if the CLUES model had been calibrated to statistics that were an accurate reflection of the current state.

20. The likely biases in the adopted parameter values for the CLUES model would have flowed through to all of the scenarios simulated with the model. In this case, it is likely that the concentrations produced by the CLUES model for the 1863 scenario are likely to be under simulated, when compared with simulation results that would be produced by a model with unbiased parameters. The results from the 1863 scenario modelling presented in Doole et al. (2016) demonstrated that the 80-year water quality objectives would generally have been achieved. However, if the constituent concentrations predicted from the 1863 scenario modelling were too low, then more accurate modelling of the 1863 scenario may demonstrate that the 80-year water quality objectives, at least for some constituents at some locations, may not be achieved.

21. Semadeni-Davies et al. (2016) calculated “calibrated apparent attenuation” factors in each model sub-catchment, which were quoted in Table 3-2 of Semadeni-Davies et al. (2016) for TN. Semadeni-Davies et al. (2016) then adopted “adjusted apparent attenuation” factors in each model sub-catchment, which were also listed in Table 3-2 of Semadeni-Davies et al. (2016). According to the discussion in section 3.1.2 of Semadeni-Davies et al. (2016), the “adjustment” was made to the attenuation factors in sub-catchments to have attenuation factors in the range between 0 and 1, which is consistent with physical reasoning that there would be some uptake of TN between the point of generation in the landscape and delivery to the sub-catchment outlet, and “on the basis of information provided by the expert panel” (Semadeni-Davies et al., 2016, p. 20). Further discussion to justify the adjustments made to the “adjusted” attenuation factors is provided on pp. 23-24 and Appendix J of Semadeni-Davies et al. (2016).

22. As CLUES is a steady-state model, by default it assumes that the water quality statistics predicted from the model for a given period of time are determined by the characteristics of the upstream catchment that existed over the same period of time. Semadeni-Davies et al. (2016) was calibrated to water quality parameters that were computed over the period 2010-14, with a representation of the land use in the catchment over the concurrent period, i.e. 2010-14.

23. Semadeni-Davies et al. (2016) recognises that there is a time lag between drainage of water and dissolved contaminants at the base of the root zone and that same water and dissolved contaminants arriving in the stream. As discussed in Mr Williamson’s evidence, the time lag between generation of the drainage water and dissolved contaminants in the root zone and the appearance of the associated water and constituents in the stream varies considerably (weeks to decades in some cases) due to variations in the soil and geology in sub-catchments, the vertical depth from the surface to the water table and the horizontal distance between the point of generation, and the point at which that groundwater discharges to a stream.

24. As CLUES is a steady-state model, it cannot explicitly represent the variable time lag between generation of constituents at the root zone of a particular land use in a particular sub-catchment and the point where those constituents are observed in-stream. In effect, the water quality statistics calculated from monitoring data for the calibration period, 2010-14, were actually a reflection of contaminants generated from land use over some undefined longer period prior to 2014.

25. Mr Williamson demonstrates in his evidence that,

> “a fundamental premise of the provisions in PC1, specifically the concept of groundwater N ‘load to come’, is conceptually flawed - because it is inconsistent with scientific principles of redox chemistry, and lacks scientific observation data and robust modelling support” (Summary, paragraph 1).

26. Mr Williamson explains that:

> There is no evidence of old groundwater discharges having high nitrate loads, and the explanation that the effects of past land use changes have not yet materialised in the receiving environment (due to groundwater lag) is unlikely to arise (in terms of probability) from a catchment management perspective and is not supported by fundamental principles of groundwater science … (Summary, paragraph 3)

27. Semadeni-Davies et al. (2016) adjusts for the shortcomings of CLUES as a steady-state model using a single measure, by modifying the "apparent" sub-catchment attenuation factors that were adopted for modelling the scenarios (including the adopted Scenario 1) to represent "ultimate" sub-catchment attenuation factors. Where changes were made between the "adjusted" and "ultimate" attenuation factors, the justification for these changes is limited to the short descriptions in the "load to come" column of Table 3-2, the discussion on pp 23 and 24 and the sub-catchment descriptions in Appendix J of Semadeni-Davies et al. (2016).

28. The CLUES modelling assumes that there is significant TN "load to come", particularly in the Upper Waikato, PC1 sub-catchments 74, 73 and 66 of the plan, which correspond to sub-catchment numbers 1, 2 and 3 of Semadeni-Davies et al. (2016). The assumptions about TN attenuation, in turn, influence the projected changes in land use that were produced for each of the scenarios to achieve the objectives.

29. The CLUES modelling is heavily dependent upon the assumptions made about current and future attenuation of TN in the groundwater. The difference between these two rates of attenuation determines the load to come of TN in the groundwater. The estimates of apparent (or current) attenuation are derived via the fitting process of the CLUES model to observed annual loads. There is some uncertainty about the apparent rates of TN attenuation. There would appear to be much more uncertainty about the assumed ultimate, or future, attenuation coefficients, as these were apparently selected via an expert panel process. There is little in the way of further objective evidence, in the technical reports, to support the attenuation coefficients that were adopted for TN for the ultimate case. Mr Williamson's evidence explains the flaws in the "load to come" concept for TN, which was implemented by specifying ultimate attenuation factors in the CLUES modelling.

30. E. coli is inherently difficult to model at catchment scale, due to the large temporal and spatial variations in generation, delivery to stream and decay of E. coli in the catchment. The approach taken by Semadeni-Davies et al. (2015) was to develop three separate regression models: for mean annual loads, median concentrations, and 95th percentile concentrations. The three regression models were similar in mathematical structure to CLUES or SPARROW models.

Semadeni-Davies et al. (2015) optimised the model to fit values to parameters for mean annual generation rates for five different land use types (dairy, intensive sheep and beef, high and hill country sheep and beef, urban and "other rural land uses" - which for the latter includes plantation forestry, native forest and scrub, horticulture, cropping and all other types of stock). Their model also included calibration parameters that adjusted generation rates between well and poorly drained soils (two categories), generation rates factored by mean annual rainfall, and allowance for decay of E. coli in the eight hydro-power generation and three shallow lakes.

31. It is important to note that the Semadeni-Davies et al. (2015) modelling did not discriminate generation rates based upon the implementation, or otherwise, of mitigation measures within each land use. In other words, all the dairy land use from across the entire Waikato catchment, had the same baseline generation rate per unit area for E. coli, with the only modifications to the baseline generation rates being for soil class and mean annual rainfall. This is a simplistic approach that does not allow for the potentially appreciable differences in generation and delivery of E. coli to stream that would be expected with and without mitigation measures, such as stream fencing and/or re-vegetation of the riparian zone.

32. Appendix A of Semadeni-Davies et al. (2015) provides a literature review of studies into mitigation measures for E. coli. Whilst it is acknowledged that quantifying the effect of mitigation measures on E. coli generation and delivery is difficult, the lack of a factor to represent mitigation measures in the Semadeni-Davies et al. (2015) model does:

    a. Compromise its ability to make accurate assessments, for current conditions, of the spatial variations in E. coli loads within each of the five land use classes where there may be variations within some of the land use classes in mitigation measures that are currently implemented; and

    b. Compromise its ability to make accurate projections about how future implementation of mitigation measures will modify E. coli loads and concentrations.

The relative importance of phosphorus and nitrogen

33. Verberg (2016) provides a strong case that the most important causative driver for algal blooms, as indicated by Chlorophyll-a concentrations, is elevated concentrations of Total Phosphorus (**TP**) during the growing season.

34. Verberg (2016) makes a compelling case for this position, supported by statistical analysis. He states (p 5) that:

> There is abundant evidence that algal biomass in the Waikato River is primarily limited by phosphorus (P), and not by nitrogen (N)… the long term trends showing TP and chlorophyll a to have decreased while TN increased … Reduced P concentrations in the Waikato River in the past two decades appear to have been responsible for the trend of reducing average algal biomass in the river. The decrease in algal biomass was achieved without reducing N.

35. In comparing the relative importance between N and other contaminants, including Phosphorus (**P**), paragraph 131 of the Section 42A Report also states that, "on balance the River system would appear to be more sensitive to increases or reductions in P load." It appears from reading paragraph 131 of the Section 42A Report that the focus in PC1 on controlling N loads was related to N as a "good indicator of farming intensity", rather than a causative link between N export and achieving verifiable water quality outcomes, such as a reduction in chlorophyll-a concentrations.

36. I support Verberg's conclusions with regard to the importance of P as a predictor of algal biomass in the Waikato River. It makes sense, therefore, that the focus of limitation of nutrient discharges should be on changes in TP discharge. The corollary of this is that there should be much less priority placed, in PC1, on limiting discharge of TN and Dissolved Inorganic Nitrogen (**DIN**). However, the primary control expressed in PC1 at the moment is on limitation of TN discharge, via the Nitrogen Reference Point (**NRP**) mechanism included in the rules and Schedule B.

Development of the Ruahuwai Decision Support Tool (RDST) by WPL

37. Paragraph 504 of the Section 42A Report expresses the concerns of the Officers that:

> Any substantial changes or redefining of sub-catchments may mean that the outcomes of the modelling no longer apply and would need to be re-modelled. As the targets and limits have been developed using existing monitoring data, changing the sub-catchments may lead to changes to the limits and targets set in Table 3.11-1, which is not a simple exercise.

38. The recommendation of the Officers is that PC1 should not change because it is not possible to undertake revised modelling. Paragraph 506 of the Section 42A Report argues that sub-catchments should not be subdivided from those currently articulated in PC1, on the basis that "monitoring data and information" needs to improve before this should occur. Paragraph 552 of the Section 42A Report limits the sub-catchments to the 74 sites where WRC have set aside funding to set up and monitor water quality.

39. The sub-catchment delineation adopted by WRC for PC1 appears to have mainly been determined by the method of data analysis and modelling approach adopted to support the CSG, instead of fundamental differences in hydrological or water quality response between sub-catchments. The modelling approaches adopted for HRWO, including the CLUES model (Semadeni-Davies et al., 2015 & 2016), are limited to site based assessments, generally at locations with water quality monitoring data. The sub-catchment definition in PC1 was determined by limitations in the modelling approach and method of analysis adopted.

40. In my experience, it is possible to develop an alternative modelling framework that would allow water quality outcomes to be predicted, with some level of confidence, at locations other than those with existing monitoring data. This would allow subdivision of the existing sub-catchments set out in Table 3.11-2 of PC1. Alternative models could also be dynamic seasonal, monthly or daily timestep models, which could overcome the concerns that I have expressed about the shortcomings of CLUES as a steady state model. An alternative model could therefore produce defensible outcomes for PC1 to support an alternative arrangement of sub-catchments to those set out in Table 3.11-2 (e.g. by subdividing Sub-catchment 66 as requested by WPL).

41. WPL have funded development of the RDST. The RDST approaches the PC1 process through a process-driven modelling platform that can provide a ‘catchment calculator’ across a region with known bio-physical specifications and management practices. Thus, while WRC has resolved to utilise a generic, single model indicator across the broader Waikato and Waipa catchments, WPL has in contrast specifically focused on a more restricted area, with a significant history of research and monitoring and known historical land use development, and with pre-determined future development scenarios, when compared to lower reaches of the Waikato River catchment.

42. The RDST is comprised of a series of coupled models that replicate the hydrological, water quality and biophysical response of the Ruahuwai sub-catchments (described below). The technical evidence supporting the WPL submissions is produced from simulations performed using the RDST. The Ruahuwai sub-catchments cover the upper portion of the Waikato River catchment, or the portion of the catchment between Taupo gates and Ohakuri Dam. The area represented by the RDST is very similar to ten of the most-upstream sub-catchments referred to in the Section 32 Evaluation Report, designated with sub-catchment numbers 56 (Whirinaki), 58 (Waiotapu at Campbells Road), 59 (Otoamakokore), 62 (Kawaunui), 65 (Waiotapu at Homestead), 66 (Waikato at Ohakuri Dam), 69 (Mangakara), 72 (Torepatutahi), 73 (Waikato at Ohaaki Bridge) and 74 (Pueto). The WPL land holding (**the Estate**) is located entirely within part of the area represented by the RDST (namely, sub-catchments 66, 72 and 73).

43. The RDST was set up as a transient model that allowed for temporal changes in land use, developed to explicitly represent the spatial and temporal changes in land use and farm practices and demonstrate the transient responses in water quality over time. Comparisons between water quality monitoring results and model outputs from a transient model framework explicitly allow the model to make defensible forecasts of future water quality outcomes, given land use changes that have occurred in the past and forecast changes in land use and farming practices. This contrasts with the steady-state CLUES model, which cannot explicitly represent the temporal dynamics of a catchment that has changed over time and which is subject to climate variability and projected climate change.

44. The RDST adopts a transient modelling framework, operating on a daily time step. The RDST allows for finer spatial discretisation of response, with the overall Ruahuwai catchment separated into 415 sub-catchments, in contrast to the 10 sub-catchments that were adopted by Semadeni-Davies et al. (2015 & 2016).

45. The approach adopted by Semadeni-Davies et al. (2015 & 2016) does not explicitly consider the separate processes that contribute to attenuation of each constituent within sub-catchments, lumping them into a single factor.

46. Therefore, all contributions of a constituent within a sub-catchment have equal influence on the output statistics, regardless of the spatial location, within a sub-catchment, where the constituent is generated and the biophysical processes acting on that constituent between the point of generation on-farm and its delivery to stream.

47. Semadeni-Davies et al. (2015 & 2016) cannot explicitly represent mitigation actions that would mitigate delivery of constituents from a large up-slope area that is comprised of one or more land uses. For example, a riparian buffer zone would be expected to filter and remove TP from an up-slope contributing area that may be comprised of mixed dairy, dairy support and forested land uses but this would be difficult to reliably assess using the approach adopted by Semadeni-Davies et al. (2016) of lumping attenuation at the catchment scale.

48. The RDST was used to simulate the response of flow and water quality in the Ruahuwai sub-catchments under various scenarios for land and water management. The initial scenarios that were modelled by the RDST represented a continuation of current land use and land management practices (as at October 2016) for all of the Ruahuwai sub-catchments outside of the boundary of the Estate. Within the boundary of the Estate a land use change scenario was modelled to represent land use in 2018, which was consistent with the range of land uses represented in the evidence of Mr Conland.

49. The RDST was also run for a calibration scenario, which represents the current understanding of the land use change that has occurred

within the Ruahuwai area over the period between January 1972 and June 2018 inclusive. The calibration scenario was used to demonstrate the accuracy of the RDST in representing flow and water quality over the calibration period, by comparison with monitored stream flow, groundwater and water quality data. All of the simulations conducted in the RDST were run for a standard climate reference period, which commences on 1 January 1972 and concludes on 30 June 2018.

50. Simulations performed with the RDST for scenarios therefore reflect the climatic variability for the adopted climatic reference period (01/01/1972 – 30/06/2018) but with the land use and land management practices applied for the particular reference scenario. The RDST runs on a daily time step and hence the results from each RDST simulation estimate changes in the probability distribution of flow and water quality parameters, as well as statistics for mean annual flow and loads and median and 95th percentiles for constituent concentrations.

51. Final calibration and scenario runs for the RDST are currently being undertaken. It is my understanding, based upon conversations with Mr Williamson, that reports and results from the RDST will be completed and available prior to Block 2 of this hearing.

52. As the RDST already exists, it provides a viable alternative approach for setting water quality states and testing rules and provisions of PC1 against the Vision and Strategy for the plan change. The definition of sub-catchments and locations listed in Table 3.11-1 of PC1 should therefore not be limited to the locations that have been modelled in CLUES (Semadeni-Davies et al., 2015 & 2016).

Conclusions

53. There are aspects of the hydrological and water quality modelling that are not adequate in accurately capturing the hydrological and water quality response of the Waikato River catchment (particularly in relation to the Upper Waikato sub-catchments). In my view, these deficiencies in modelling contaminants therefore undermine the reliability of conclusions made using the modelling to support the argument that PC1 fulfils the requirements of the RMA.

54. Contaminant loads for Scenario 1 (that underpins PC1) at locations along the Waikato River were derived from modelling undertaken in CLUES (Semadeni-Davies et al., 2015 & 2016). CLUES is a steady state model. A key assumption of the model is that the statistics for water quality attributes produced by the model are produced in response to attributes describing the catchment state over a contemporaneous period. CLUES cannot explicitly represent the dynamics of a catchment that is changing over time, such as changes in land use, delays induced by processes that occur in catchments, multi-year or multi-decadal climate variability or climate change.

55. Calculation of statistics across a five-year analysis period (2010-14) would, in general, result in smoothing out seasonal, i.e. within year, variations due to, for example, within year climatic variation. However, I do not support a generalisation that the five-year period selected to establish the current state statistics, 2010-14, would produce an unbiased statistical assessment of the current state for water quality. This is because (a) some processes, such as generation and transport of dissolved N via groundwater flow pathways occur over periods that may be substantially longer than five years and (b) the catchment responds to trends and variations in climate that are subject to cycles that are longer than five years.

56. The sub-catchment delineation adopted by WRC for PC1 appears to have mainly been determined by the method of data analysis and modelling approach adopted to support the CSG, instead of fundamental differences in hydrological or water quality response between sub-catchments. The sub-catchment definition in PC1 was determined by limitations in the modelling approach and method of analysis adopted.

57. In my experience, it is possible to develop an alternative modelling framework that would allow water quality outcomes to be predicted, with some level of confidence, at locations other than those with existing monitoring data. An alternative model would also be a dynamic model, which could overcome the concerns that I have expressed about the shortcomings of CLUES as a steady state model. An alternative model (such as the RDST) could therefore produce defensible outcomes for the plan to support an alternative arrangement of sub-catchments to those set out in Table 3.11-2 of PC1.

58. WPL has funded a considerable modelling effort to understand, appreciate and develop the RDST process in light of sustainable (preferred) economic, social and environmental outcomes. The RDST is comprised of a series of coupled models that replicate the hydrological, water quality and biophysical response of the Ruahuwai sub-catchments. The technical evidence supporting WPL's submissions is produced from simulations performed using the RDST.

59. The RDST was set up as a transient model that allowed for temporal changes in land use, developed to explicitly represent the spatial and temporal changes in land use and farm practices and demonstrate the transient responses in water quality over time. Comparisons between water quality monitoring results and model outputs from a transient model framework explicitly allow the model to make defensible forecasts of future water quality outcomes, given land use changes that have occurred in the past and forecast changes in land use and farming practices. This contrasts with the steady-state CLUES model, which cannot explicitly represent the temporal dynamics of a catchment that has changed over time and which is subject to climate variability and projected climate change.

60. Final calibration and scenario runs for the RDST are currently being undertaken. It is my understanding, based upon conversations with Mr Williamson, that reports and results from the RDST will be completed and available prior to Block 2 of this hearing.

61. As the RDST already exists, it provides a viable alternative approach for setting water quality states and testing rules and provisions of PC1 against the Vision and Strategy for PC1. The definition of sub-catchments and locations listed in Table 3.11-1 of PC1 should therefore not be limited to the locations that have been modelled in CLUES (Semadeni-Davies et al., 2015 & 2016).

Phillip William Jordan

Principal Hydrologist, Hydrology and Risk Consulting

15 February 2019

HARC
hydrology and risk
CONSULTING

Phillip Jordan

Current Position

Principal Hydrologist at Hydrology and Risk Consulting

Qualifications

Bachelor of Engineering (Civil) (Hons.), University of Queensland, 1989

Doctor of Philosophy, Monash University, 2001

Professional memberships and affiliations

Member, Engineers Australia and Chartered Professional Engineer (C.P.Eng.)

Registered Professional Engineer in Queensland

Fellow of the Peter Cullen Water and Environment Trust

Expertise

Integrated catchment models for water quantity and quality

Flood hydrology and hydraulic modelling

Analysis of radar rainfall data and application to modelling of streamflow

Dam failure consequence and risk assessments

Incorporating impacts of climate change in hydrological modelling

Development of specialist computer code for hydrological modelling

Summary of Competencies

Dr Phillip Jordan has twenty years of experience in hydrology and water resources engineering. Phillip was the Product Project Leader for the development of eWater's Source Catchments modelling package and has extensive experience in applying Source to water quality modelling. Phillip was engaged as an expert witness for the Queensland Floods Commission of Inquiry in 2011. Phillip has applied both Monte-Carlo simulation and continuous simulation techniques to flood hydrology and is at the forefront of industry best-practice. He was lead author of the chapters on Areal Reduction Factors and Spatial Patterns of Design Rainfall in the 2016 update of *Australian Rainfall and Runoff*, the Australian guideline on flood hydrology. Phillip has been an author or co-author of more than 50 conference and journal papers. Phillip is a Fellow of the Peter Cullen Water and Environment Trust and he was Chairman of the Organising Committee for the 2018 Hydrology and Water Resources Symposium in Melbourne.

Employment History

Hydrology and Risk Consulting (HARC), Melbourne	***Nov 2015 – current***
Jacobs and Sinclair Knight Merz, Melbourne and Brisbane	***Jan 2003 – Oct 2015***
Bureau of Meteorology, Melbourne	***Jul 2001 – Dec 2002***
SMEC, Melbourne	***Mar 2000 – Jun 2001***
Queensland Water Resources Commission, Ayr and Brisbane	***Jan 1994 – Feb 1997***

Relevant Project Experience

- **eWater Source integrated water quantity and quality modelling platform, Product Project Leader (2005-2012)** Led the development of the eWater Source catchment modelling project, including technical direction of software development activities. Major achievements were the delivery of the rainfall runoff calibration tool, improvement in software stability and run-times for catchment modelling and delivery of several custom rainfall-runoff models.
- **South East Queensland Healty Waterways and Catchments 2016 Report Card**: Update and calibration of eWater Source models to simulate flow and water quality delivered from the Brisbane, Logan, Albert, Maroochy, Mooloolah and Noosa River catchments, which were then fed into TUFLOW-AED models of receiving waters to simulate receiving water quality for 2015/16.
- **Catchment water quality modelling for the Kaituna and Rangitaiki River catchments**: Williamson Water Advisory, HARC and Ecological Australia developed flow and water quality management models for the Kaituna and Rangitaiki Rivers in the Bay of Plenty Region of New Zealand. These models were implemented in Source and produced daily time series of flows and loads of nutrients, sediment and E. coli.
- **Ruahuwai (Waikato River Catchment) Flow and Water Quality Assessment**: Development of eWater Source model of the Waikato River catchment from downstream of Lake Ohakuri to the Waikato River estuary, including the middle and lower Waikato River and Waipa River catchment; Development of customised plugin for reporting flow and water quality results from the model; Review of detailed flow and nutrient load model for the Upper Waikato River from Lake Taupo to Lake Ohakuri, including calibration and modelling of potential development scenarios for the Wairakei Estate.
- **Cherry Lake Stormwater Recycling Scheme**: Technical review of water balance model to estimate size of storage pond to achieve desired reliability of supply from stormwater re-use system; MUSIC model of the proposed off-stream stormwater recycling scheme to estimate projected reductions in TN load and concentrations
- **Selwyn-Waihora Catchment** Flow and Water Quality Assessment: Developed an eWater Source Catchments model of the Selwyn-Waihora zone; Applied scenarios to analyse the impact of forecast increases in irrigated agriculture on in stream Nitrogen concentrations (including nutrient species) and loads delivered to Lake Ellesemere / Te Waihora; Preparation of Expert Witness Statements
- **Tukituki River Catchment** Flow and Water Quality Assessment: Developed an eWater Source Catchments model of the Tukituki River Catchment; Applied scenarios to analyse the impact of forecast increases in irrigated agriculture on in stream Nitrogen and Phosphorus concentrations (including nutrient species); Applied scenarios to analyse the impact of proposed changes in minimum flow rules in the catchment on water availability for irrigators;
- **Hawkesbury-Nepean Integrated Water Quantity and Quality Model**: Lead the development of an eWater Source model for the entire Hawkesbury-Nepean basin; Calibrated the rainfall runoff model parameters of the model to observed flows; Developed customised tools for integration of point rainfall into the Source model; Developed customised plugins for the eWater Source model to enable input of Wastewater Treatment Plant inflows to the model
- **Brisbane Catchment Dams and Operations Alternatives Study**: Development of stochastic framework in URBS for producing 5000 simulated hydrographs of possible floods in the Brisbane River catchment, to be used for testing of alternative operational strategies for Wivenhoe and Somerset Dams; Flood frequency analysis of flows and volumes at key gauging stations within the Brisbane River catchment; Development of stochastic generator for plausible spatial and temporal patterns of design rainfall across the Brisbane River basin
- **Independent Expert Witness to Queensland Floods Commission of Inquiry**: Provided expert witness statement on flash flooding and adequacy of warnings for the flash floods that occurred in Toowoomba and Lockyer Valley on 10 January 2011; Provided expert witness statement on the effect of Wagners Quarry on flash flooding in Grantham on 10 January 2011
- **Author of Australian Rainfall and Runoff (2016)**: Lead author of two chapters of Australia's national flood guidelines: on use of spatial and space-time patterns of rainfall in design flood estimation and on areal reduction factors for design rainfall estimates.

- **Bruce Highway Flood Link Study**: Development and application of an innovative continuous simulation technique to estimate flood hyrographs over a 100 year period, at hourly resolution, for 522 crossings along the Bruce Highway, between Brisbane and Cairns; Calibration of the continuous simulation method to gauged flows at 56 available flow gauge sites; Automation of the procedure within the eWater Source modelling package. Climate change sensitivity analysis scenario was also run for each of the crossings.
- **Melbourne Stormwater Quantification Tool**: Developed an eWater Source Catchments model of the entire Melbourne Water area; Developed a customised plugin that estimated, on a catchment by catchment and total upstream area basis, the available harvestable volume of additional storm water that is derived from urban parts of the Melbourne Water area
- **Nerang River Catchment** Freshwater Health Study: Developed an eWater Source model for flow and water quality of the Nerang River catchment to Hinze Dam; Estimation of the impact of various mitigation measures to improve water quality entering Hinze Dam, using the eWater Source model
- **Review of Modelling frameworks for Water Quality in the Murray Darling Basin**: Comparison of a dozen different potential water quality modelling systems for their applicability and ease of use at a basin level within the Murray Darling Basin
- **Impact of harvestable rights farm dams in coastal NSW catchments**: Investigated how the potential impact of changes in harvestable rights policy could modify water availability for ten case study catchments in the coastal region of New South Wales. STEDI models in each catchment, were run for 40 scenarios in each catchment, by including potential new farm dams that could be constructed with the harvestable rights policy modified to permit larger dam volumes and/or dams located on up to either second or third order streams.
- **Hydrological modelling of the impact of potential changes in land use across Victoria**: SoilFlux is a one-dimensional model of the unsaturated zone of the soil profile, which was used to calculate the impacts of changes in land use on catchment scale water balance. We ran 800,000 SoilFlux runs, to update the SoilFlux Tools inputs for every 1 km² grid cell across Victoria with revised depth to water table and climatic data inputs.
- **Modelling of farm dam impacts for eleven catchments in Victoria**: Modelling of impacts of farm dams on water availability in eleven Victorian catchments using the Spatial Tool for Dam Impacts, or STEDI, model. The project included spatial analysis of a DEM to determine the total upstream catchment area of each dam and the catchment area between successive dams.
- **Guidelines for modelling wetlands in Source:** wrote an easy to apply guideline to assist DELWP to read environmental watering plans for wetlands and then translate these into the appropriately configured modelling components in Source models. HARC applied the guidelines to include the Doctors Swamp and Reedy Swamp wetlands into the Goulburn River basin Source model.
- **Trends in farm dam development over time for Victoria**: Analysis of trends in farm dam growth across Victoria over the period between 2000 and 2015. Trends were estimated by digitising changes in farm dams from available imagery across a 1500 km² sample area, spread across Victoria. Statistical analysis was completed to update the baseline data set on farm dams, to provide projected annual estimates for 2000 to 20205, as a component of Victoria's "take" under the Murray Darling Basin Plan.
- **Update of evapotranspiration tools for Victoria**: Updating of an Arc-GIS interface that produces estimates of evapotranspiration, surface runoff and deep drainage on a catchment-by-catchment basis across Victoria. The tool allows for evapotranspiration to be updated on an annual basis with land use and land cover data from the Victorian Land Use Information System and gridded data on the annual rainfall total for the year. The system runs on a 1 km grid cell basis across the state, with evapotranspiration estimates interrogated from results of 110,000 one-dimensional hydrological model runs for ten different land use types and for combinations of climate regions, soil types and depth to water table. Project involved development of software code in VB.NET implementing ArcObjects and geoprocessing tools within ArcGIS.
- **Peak Urban Water Demand for Melbourne**: Statistical analysis of trends in peak hourly demand over the period between 2000 and 2014 for Melbourne Water daily water demand and for a growth area (Pakenham)

- **Farm Dam Impacts in the Woori Yallock Creek Catchment**: Technical Reviewer, Use of the eWater Source tool to identify the set of dams (of the 2800 in the catchment) that are having the largest impact on summer baseflows, identification and testing of management options to improve flows during summer and autumn.
- **Impact of Stock and Domestic Farm Dams on Water Resources in Queensland** :Captured and synthesised remote sensing data on the surface area of farm dams across Queensland; Developed Queensland specific regional prediction equations to estimate the storage volume of farm dams across each catchment of Queensland; Modelling the impact on flow of stock and domestic farm dams for 160 catchments across Queensland and regionalisation of water resources impact to the whole of Queensland
- **Sustainable Diversion Limits for South West Western Australian Catchments**: Estimation of sustainable diversion limits for water from unregulated catchments in South West Western Australia. This project involved analysis of hydrological data from 160 catchments, use of an expert panel process to set the sustainable diversion limits in the gauged catchments and regionalisation of the results for application to 1900 ungauged catchments completely covering southwest WA
- **Murray Darling Basin Sustainable Yields Project**: Modelling projected effects of future farm dam impacts on runoff from every subcatchment in the Murray Darling Basin, as part of the 2007 Sustainable Yield study.
- **Stochastic Data Generation for Canberra Water Resources Strategy**: Stochastic generation of climate data series for the Canberra Water Resources Strategy. Stochastic data was applied to rainfall-runoff and demand models to quantify water availability and security of supply for Canberra. Potential effects of climate change were incorporated into the model.
- **Assessment of Water Quantity and Quality Impacts of Proposed Coal Seam Gas Permeate Discharge into Glebe Weir**: Lead development of an eWater Source model of the Dawson and Fitzroy River systems, including Glebe Weir to model water quality in the system. Development and testing of impacts from various scenarios for discharge of permeate and re-use of the permeate for irrigation downstream of Glebe Weir.
- **Assessment of Water Quantity and Quality Impacts of Proposed Coal Seam Gas Permeate Discharge into Chinchilla Weir**: Lead development of an eWater Source model of the Balonne River system, including Chinchilla Weir to model water quality in the system. Development and testing of impacts from various scenarios for discharge of permeate and re-use of the permeate for irrigation downstream of Chinchilla Weir.
- Water quality model of **Hornsby Shire**: Development of an eWater Source catchment model of Hornsby Shire (then known as E2), including customisation of model framework using the TIME modelling environment
- **Avon Plains Lakes Water Management Plan**: Hydrological analysis of options for inflows to Hancocks, Walkers and Hollands Lakes, three ephermeral lakes on the Avon River floodplain. Hydrological modelling was run to test options for structures in Hollands Bank, to permit diversion of flood flows into the lakes and the associated changes in ecological values for the lakes.
- **Catchment model of Inflows to Googong Dam**: Development of a Source catchment model of the Queanbeyan River catchment in the ACT to assess the relative impacts of farm dams, groundwater pumping and changes in vegetation response on streamflow yields to Googong Dam during the Millenium Drought.
- **Design flood hydrology for catchments upstream of Eildon and Nillahcootie Dams**: Developed representative hydrographs as inputs to hydraulic modelling of design floods along the rivers and floodplains upstream of Eildon Reservoir and Lake Nillahcootie. This project involved updating the catchment subdivision to provide sufficient spatial resolution for hydraulic modelling, re-calilbration of the RORB models to the 1975, 1993, 1998, September and December 2010 flood events, verification of design parameters to flood frequency analysis and development of representative hydrographs (for single event hydraulic modelling) for Fords Creek, Delatite River, Howqua River, Big River, Goulburn and Jamieson rivers and the Broken River.
- **Extreme rainfall frequency estimates for Hume and Dartmouth Dams**: Technical lead in applying one of the two techniques (Stochastic Storm Transposition method) to estimate design rainfall in the large and extreme range (1% AEP to the Probable Maximum Precipitation). Task

involved improvement and customisation of computer code for the method, analysis of data to provide appropriate inputs for the method and application of the method.

- **Googong Dam, Review of December 2010 Flood for Queanbeyan**: RORB modelling to simulate impact of December 2010 flood event on peak flood flows through Queanbeyan under potential strategies of creating airspace in Googong Dam via existing outlet works and costs that would be incurred on Canberra water supply system from creating airspace and potential impacts on recreational amenity of drawing down Lake Burley Griffin. Project involved delicate treatment of stakeholder consultation with Icon Water, Queanbeyan City Council and National Capital Authority.
- **Melbourne Metro Rail Tunnel Preliminary Design**: Review of RORB modelling to derive design flood estimates for 1%, 0.1% and 0.01% AEP flood events, including projected effects of climate change, for preliminary design of tunnel portals and stations.
- **Yarralumla Creek, Long Gully and Weston Creeks Flood Studies**: Preparation of design flood maps and GIS outputs, for existing conditions, for the three catchments; Investigation of flood mitigation detention basins near Mawson
- **Huntley Road Bypass Project, New Zealand**: Review of approaches for estimation of design floods (1% and 0.05% AEP) for highway crossings
- **Flinders Highway Flood Study**, North Queensland: Development and application of an innovative continuous simulation technique to estimate flood hyrographs over a 100 year period, at 3 hourly resolution, for each of 134 crossings along the Flinders Highway; Calibration of the continuous simulation method and 3 hourly flow disaggregation method to gauged flows at available gauge sites; Automation of the procedure within the eWater Source modelling package
- **Upgrades to Pacific Highway**: Nambucca Heads to Urunga and Urunga to Ballina: Review and development of rainfall runoff models in WBM and RAFTS for drainage crossings of the highway; Verification of estimated design peak flows under pre-upgrade conditions using regional flood frequency analysis and the rational method
- **Estimation of large and extreme design rainfall intensities for New South Wales and the Australian Capital Territory using the CRC-FORGE method**: Development of extreme rainfall database for NSW and ACT using the CRC Focussed Rainfall Growth Estimation method, Development of Areal Reduction Factor curves for NSW and the ACT
- **Research into Dual Polarisation Radar Technology for Quantitative Rainfall Estimation** and Flood Forecasting, Bureau of Meteorology: Coding of the Mapview software for viewing and manipulating radar rainfall data in C++; Development of an integrated system for using radar measured rainfall accumulations in real-time flood forecasting operations for the Georges River, near Sydney; Research into practical application of dual-polarization radar for rainfall measurement and flood forecasting; Analysis of weather radar data from the April 1999 Sydney Hail Storm, concentrating on the effect of attenuation on the relative performance of the two radars in Sydney; Research into new spatial and temporal patterns for design-event rainfall using radar rainfall data.
- **Upgrade of South Gippsland Highway, Sale, Victoria**: Two-dimensional hydraulic modelling of floods at the junction of the Thomson and Latrobe Rivers using RMA-2 software
- **Catchment model of Inflows to Googong Dam**: Development of customised eWater Source model of the Queanbeyan River catchment in the ACT to assess the relative impacts of farm dams, groundwater pumping and changes in vegetation response on streamflow yields to Googong Dam during the Millenium Drought.
- **Influence of rainfall intensities on landuse risks for Tasmania**: Derivation of rainfall depths for use in assessment of landslide risks across Tasmania.
- **Remote sensing of evapotranspiration using SEBAL to water resources assessment in Southern Australia**: Application of the SEBAL technique for remote sensing of evapotranspiration to estimate water balances for four case study regions in south eastern Australia.
- **Update of the REALM model for the Tarago/Bunyip supply system**, Victoria: Derivation of unimpacted and current daily flow time series for monitoring locations in the Tarago/Bunyip catchment system, Victoria.

- **Development of Sustainable Diversion Limits for Victoria**: Writing of FORTRAN computer code for the STEDI model, which is used to perform water balance computations for individual farm dams within a catchment based on GIS information.
- **Development and Review of Water Demand Management Plan for Auckland Area**, New Zealand: Technical assistance and review to Watercare in Auckland, New Zealand with the development of their water demand management plan.
- **Water Management Plan for Avon Plains Lakes**: Development of a water management plan for three ephemeral lakes in the Avon River Plains.
- **Barmah Choke Study**: Modifications to the FORTRAN code for the MSM and Bigmod models, to assess the impact of water trading on supply constraints for the Murray River: Project management and technical roles
- **Update of REALM Version of Murray Simulation Model**: Updating and customisation of FORTRAN code for the monthly REALM water resources simulation model of the Murray River.
- **Irrigation Channel Automation, Northern Victoria**: Statistical trend analysis to estimate measurement accuracy for Dethridge wheel flow meters in the Katandra Invergordon irrigation district, northern Victoria.
- **Trends in Peak Hourly Urban Water Demand, Melbourne**: Statistical analysis of changes in peak hourly demand associated with demand management initiatives for residential zones in South East Water's service area, Melbourne.
- **Burdekin Falls Dam Flood Hydrology**: Re-assessment of flood hydrology for Burdekin Falls Dam. RORB models were set up for the BFD catchment, based upon existing URBS models. RORB models were calibrated to gauged flows for 14 historical events. RORB model was verified to flood frequency analysis at four locations within the catchment, including a 100 year composite gauge record at Clare. Space-time rainfall patterns were derived for the BFD catchment from extreme rainfall events observed across the GTSMR PMP zone and sampled in the Monte-Carlo flood estimation framework. Design flood estimates were derived for the existing dam and several upgrade options.
- **Design flood hydrology for six potential dam sites in the Mitchell and Darwin catchments**: Design flood inflows and flood volumes were developed, to inform the development of preliminary conceptual arrangements for dams at six potential sites in the Darwin (Northern Territory) and Mitchell (Queensland) catchments. Large and extreme floods were modelled using Monte-Carlo simulations in RORB.
- **Design flood hydrology for Foster Dam**: Assessed design flood hydrology of the existing dam and potential upgrade options, using Monte-Carlo simulation in RORB. The potential for blockage of spillway structure was included in the hydraulic analysis using the procedures in ARR2016.
- **Hindmarsh Valley Dam** Hydrology, Dambreak Modelling and Consequence Assessment: Flood hydrology for dam using Monte-Carlo simulation in RORB
- **Baroota Dam** Hydrology, Dambreak Modelling and Consequence Assessment: Flood hydrology for dam using Monte-Carlo simulation in RORB; Dam break modelling of six scenarios for the dam; Estimation of population at risk, loss of life, economic damages and hazard category for each of the dam break scenarios
- **Merrimu Dam** Upgrade Design: Revision of outflow flood frequency curve for the dam, incorporating verification to flood frequency analysis and joint probability of inflow floods and storage drawdown; Dam break modelling using MIKE-FLOOD and consequence assessment for several scenarios
- **Wild River Dam** Failure Impact Assessment, near Herberton, Queensland: Dam break modelling and failure impact assessment for Wild River Dam using MIKE-FLOOD, in accordance with Queensland Guidelines
- **West Angeles Mine**: Technical review of "dam break" hydraulic modelling for scenarios where a mine haul road that acts as a levee during flood events is overtopped and fails
- **NSW State Water Flood Operations Manuals**: Reviewed existing and proposed format and structure of flood operations manuals for NSW State Water's dams (both gated and ungated) and

proposed a revision to the structure of the manuals, including recommendations of content that should be included.

- **Portfolio Risk Assessment of Seqwater's 26 Dams**: Derivation of spatial layers for inundation extent, travel time from the dam and inundation severity associated with between three and eight dam failure scenarios for each of Seqwater's 26 large dams (approximately 150 scenarios in total). Spatial layers developed were used to estimate population at risk, loss of life, economic and environmental consequences associated with each scenario at each dam
- **Flood Operation of Wivenhoe, Somerset and North Pine Dams**: Senior Flood Engineer, Directed gate operations for the three dams during three minor flood events in February and March 2012
- **Corin, Bendora, Cotter and Googong Dams**: Monte-Carlo simulation of design floods and seasonal flood frequency assessment
- **Ross River Dam**: Compiled the risk assessment that was used in prioritising options for the major dam safety upgrade of Ross River Dam in North Queensland. Quantitative assessment of flood induced piping failure risk for the long earth embankment section was a major component of this work
- **Hinze Dam Upgrade Stage 3**: Application of Monte-Carlo simulation technique to estimate design flood outflow estimates from Hinze Dam resulting from the Stage 3 Upgrade
- **Dartmouth Dam**: Application of Monte-Carlo simulation technique to estimate the overall change in outflow flood risk from Dartmouth Dam under climate change, that considered the potential changes in rainfall intensities during the flood, catchment losses due to change in catchment wetness prior to floods and changes in storage within the dam prior to floods.
- **Newlyn Reservoir** Acceptable Flood Capacity Assessment: Flood hydrology assessment in stochastic framework using RORB
- **West Gellibrand, Olangola, Painkalac and Allen Reservoirs**: Design flood hydrology, hydraulic modelling and consequence assessment
- **Cairn Curran Dam**: Hydrological and hydraulic modelling for upgrades to flood capacity, included the use of radar data to improve the calibration of the RORB rainfall runoff routing model for deriving design floods
- **Eildon Dam:** Hydrological and hydraulic modelling of large and extreme floods to assess upstream impacts
- **Technical Due Diligence on sale of several Hydro Power Stations, Victoria**: Long-term hydrological and economic modelling of electricity generation for a network of hydropower stations across Victoria.
- **Eildon Dam:** Hydraulic modelling of large and extreme floods and estimation of consequences
- **Lake Buffalo**: Conceptual design of a real-time flood forecasting and warning system
- **Melton and Merrimu Dams**: Hydraulic modelling and consequence assessment
- **Spring Gully and Sandhurst Dams** : Hydraulic modelling and consequence assessment
- **Moogerah Dam**: Development of a structural finite element model of the wall and abutments of Moogerah Dam (double curvature concrete arch)
- **Borumba, Coolmunda, and Moogerah Dams**: Hydraulic modelling of dam break inundation floods
- **Bingegang Weir**: Initial planning and development of options for additional storage

Awards

- 2016 Fellow of the Peter Cullen Water and Environment Trust
- 2008 John Winton Medal for Technical Excellence and Innovation: SKM Water and Environment
- 2000 Best Presentation by a Student or Recent Graduate at Hydrology and Water Resources Symposium, Perth
- 1993 University Medalist – University of Queensland
- 2002 Transurban Excellence in Engineering Award – University of Melbourne

Technical Publications

Australian Rainfall and Runoff (2016)

Ball, J., Jordan, P., Seed, A., Nathan, R., Leonard, M. and Weinmann, P.E., *Australian Rainfall and Runoff*, Book 4, Chapter 2, Rainfall Models, Engineers Australia, released 6 July 2016.

Jordan, P., Nathan, R., Podger, S., Babister, M., Stensmyr, P. and Green, J., *Australian Rainfall and Runoff*, Book 4, Chapter 4, Areal Reduction Factors, Engineers Australia, released 6 July 2016.

Jordan, P., Seed, A., Nathan, R., *Australian Rainfall and Runoff*, Book 4, Chapter 6, Spatial Patterns of Rainfall, Engineers Australia, released 6 July 2016.

Refereed Journal Papers

Seed, A.W., Jordan, P.W., Sun, X., Srikanthan, R., and Elliott, J., Using radar to predict floods, *Water, Journal of the Australian Water and Wastewater Association*, **26**, 25-27, 1999.

Jordan, P.W., Seed, A.W. and Austin, G.L., Sampling errors in radar estimates of rainfall, *Journal of Geophysical Research – Atmospheres*, Volume **105** (D2), 2247-2250, 2000.

Jordan, P.W., Seed, A.W. and Weinmann, P.E., A Stochastic Model of Radar Measurement Errors in Rainfall Accumulations at Catchment Scale, *Journal of Hydrometeorology*, **4** (5), 841–855, 2003.

Nathan, R.J., Jordan, P. and Morden, R. Assessing the impact of farm dams on streamflows, Part I: Development of simulation tools, *Australian J. Water Resources*, **9** (1), 1-12, 2005.

Jordan, P., Nathan, R., Mittiga, L., Pearse, M. and Taylor, B. Growth curves and temporal patterns for application to short duration extreme events, *Australian J. Water Resources*, **9** (1), 69-80, 2005.

Jordan, P.W. and Hill, P.I., Use of radar rainfall data to improve calibration of rainfall-runoff routing model parameters, *Aust. J. Water Resources,* **10** (2), 139-149, 2006.

Westra, S., Ian Varley, A. Sharma, P. Hill, P. Jordan, R. Nathan, and A. Ladson. Addressing climatic non-stationarity in the assessment of flood risk, *Australian Journal of Water Resources* **14** (1), 1-16, 2010.

McMahon, T.A., A.S. Kiem, M.C. Peel, P.W. Jordan, and G.G.S. Pegram (2008) A new approach to stochastically generating six-monthly rainfall sequences based on empirical mode decomposition, *Journal of Hydrometeorology* **9** (6), 1377-1389.

Black, D., P. Wallbrink and P. Jordan, Towards best practice implementation and application of models for analysis of water resources management scenarios, *Environmental Modelling and Software*, **52** (9) 136-148, 2014.

Nathan, R., P. Jordan, M. Scorah, S. Lang, G. Kuczera, M. Schaefer and E. Weinmann, Estimating the exceedance probability of extreme rainfalls up to the probable maximum precipitation, Journal of Hydrology, http://dx.doi.org/10.1016/j.jhydrol.2016.10.044, 2016.

Conference Papers and Presentations

Jordan, P.W., Seed, A.W. and Weinmann, P.E., Effect of aggregation of rainfall in space and time on flood estimates, *24th General Assembly of the European Geophysical Society*, The Hague, Netherlands, April 1999.

Jordan, P.W., Seed, A.W. and Weinmann, P.E., Effect of spatial and temporal variability of rainfall on design flood estimates, *Water '99 Joint Congress*, Brisbane, p.649-654, July 1999.

Jordan, P.W., Seed, A.W. and Weinmann, P.E. (presented by Dr. Seed), Errors in radar measurement of rainfall – effect on flood forecasting, *25th General Assembly of the European Geophysical Society*, Nice, France, April 2000.

Jordan, P.W., Seed, A.W. and Weinmann, P.E., Errors in radar measurement of rainfall – effect on flood forecasting, *Hydro 2000, 3rd International Hydrology and Water Resources Symp.,* Institution of Engineers Australia, Perth, November 2000.

Jordan, P.W., Seed, A.W. and Weinmann, P.E. (presented by Dr. Seed), Radar measurement errors in rainfall at catchment scale, *5th International Symposium on Hydrological Applications of Weather Radar*, Kyoto, Japan, November 2001.

Jordan, P.W. and Seed, A.W., Are we taking the point too far? A problem with design temporal patterns at catchment scale, *27th I.E. Aust. Hydrology and Water Resources Symp.*, Institution of Engineers Australia, Melbourne, May 2002.

Jordan, P.W., Seed, A.W., May, P. and Keenan, T., Application of polarmetric radar to rainfall measurement in Sydney: A test of new technologies, *27th I.E. Aust. Hydrology and Water Resources Symp.*, Institution of Engineers Australia, Melbourne, May 2002.

Pearse, M.A., Jordan, P.W. and Collins, Y.L, A simple method for estimating RORB model parameters for ungauged rural catchments, *27th I.E. Aust. Hydrology and Water Resources Symp.*, Institution of Engineers Australia, Melbourne, May 2002.

Jordan, P.W., Seed, A.W., May, P. and Keenan, T., A test of attenuation correction and quality control methods for radar rainfall measurement at C-Band, *Eos Trans. AGU,* West. Pac. Geophys. Meet. Suppl., Abstract H42A-03, p.35, 2002.

Jordan, P., Nathan, R., Mittiga, L., Pearse, M. and Hill, P., Rainfall depths and temporal patterns for short duration extreme events, *Proc. ANCOLD Conference*, Hobart, November 2003.

Hill, P.I., Bowles, D., Jordan, P.W. and Nathan, R.J., Estimating overall risk of dam failure: Practical considerations in combining failure probabilities, *Proc. ANCOLD Risk Workshop*, Launceston, November 2003.

Jordan, P.W. and Hill, P.I., Use of radar rainfall data to improve calibration of rainfall-runoff routing model parameters, *29th Engineers Australia Hydrology and Water Resources Symposium*, Canberra, February 2005.

Hill, P., Sih, K., Nathan, R. and Jordan, P., The extremes of tropical hydrology, *Proc. ANCOLD Conference*, Perth, November 2005.

Hill, P., Nathan, R., Jordan, P. and Pearse, M., Development and application of a Risk Analysis and Prioritisation Tool (RAPT) for dam safety management, *Proc. ANCOLD Conference*, Sydney, November 2006.

Jordan, P.W., Argent, R.M. and Nathan, R.J., Past, present and future of catchment modelling in E2 and the eWater CRC Modelling Toolkit, *Proc. 30th Engineers Australia Hydrology and Water Resources Symp.*, Launceston, December 2006.

Jordan, P., Murphy, R., Hill, P. and Nathan, R., Seasonal response of catchment runoff to forest age, *Proc. 30th Engineers Australia Hydrology and Water Resources Symp.*, Launceston, December 2006.

Jordan, P., and Mazengarb, C., Probability of heavy rainfall events in assessing landslide risk for Tasmania, *Proc. 30th Engineers Australia Hydrology and Water Resources Symp.*, Launceston, December 2006.

Morden, R., Chapman, A., Payne, E. and Jordan, P., Impact of demand management on peak demand, *OzWater Conference*, Australian Water Association, Sydney, April 2007.

Jordan, P., R. Argent, and R. Nathan. New generation models for catchment modelling: developments in the eWater CRC, In *5th Australian Stream Management Conference. Australian rivers: making a difference*, Charles Sturt University, Thurgoona, New South Wales. 2007.

Jordan, P. W., C. R. Wiesenfeld, P. I. Hill, R. A. Morden, and Francis HS Chiew. An assessment of the future impact of farm dams on runoff in the Murray-Darling Basin, Australia, *Proceedings of Water Down Under*, p.1618, Adelaide, 2008.

Kiem, A. S., C. A. Clifton, and P. W. Jordan, Assessing the vulnerability of Victoria's water resources due to climate variability and change, *Proceedings of Water Down Under*, p. 759, Adelaide, 2008.

Lang, S., Jordan, P.W., Durrant, J. and Nathan, R.J., Defining sustainable diversion limits in unregulated south-west Western Australian catchments, *Proceedings of Water Down Under*, p.145, Adelaide, 2008.

Chiew, Francis HS, J. Vaze, N. R. Viney, J. M. Perraud, J. Teng, P. W. Jordan, D. Kirono, and W. J. Young. Estimation of Impact of Climate Change and Development on Runoff across the Murray-Darling Basin, *Proceedings of Water Down Under*, p.1957, Adelaide, 2008.

Cetin, L. T., M. Stenson, M. Gilfedder, J. M. Perraud, P. W. Jordan, and R. M. Argent, Linking Surface Water and Groundwater Models within the WaterCAST Catchment Modelling Framework, *Proceedings of Water Down Under*, p.2140, Adelaide, 2008.

Westra, S., Hill, P., Jordan, P. and Varley, I., Recent developments in climate science: Implications for Australian flood guidelines, *Proc. Stormwater Industry Association Conference*, 2008.

Cook, F. J., P. W. Jordan, and D. Waters. WaterCAST Model for Upland Hydrology-Framework and Philosophy, *In EGU General Assembly Conference Abstracts*, vol. 11, p. 123. 2009.

Cook, F. J., P. W. Jordan, D. K. Waters, and J. M. Rahman. WaterCAST–whole of catchment hydrology model: an overview. In *Proceedings of the 18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation*, Cairns, Australia, pp.3492-3498. 2009.

Cetin, L. T., L. M. Mosley, and P. W. Jordan. Assessing the Impacts of Farm Dams on the Streamflow of the Mount Lofty Ranges Watershed, In *H2009: 32nd Hydrology and Water Resources Symposium*, Newcastle, p. 1173. Engineers Australia, 2009.

Cetin, L. T., A. C. Freebairn, P. W. Jordan, B. J. Huider, R. S. Anderssen, R. D. Braddock, and L. T. H. Newham. A model for assessing the impacts of farm dams on surface waters in the WaterCAST catchment modelling framework, In *Proceedings of the 18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation*, Cairns, Australia, pp.3492-3498. 2009.

Fowler, K., Phillip Jordan, Peter Hill, Rory Nathan, and Kristen Sih Framework for incorporating available climate science in extreme flood estimates, *Climate Change 2010: Practical Responses to Climate Change*, p.364, 2010.

Sih, K., K. Fowler, P. Jordan, P. Hill, N. Nandakumar, E. Weinmann, and R. Nathan. Has there been a change in rainfall maxima?: Implications for design rainfalls, In *Proceedings of the 34th World Congress of the International Association for Hydro-Environment Research and Engineering: 33rd Hydrology and Water Resources Symposium and 10th Conference on Hydraulics in Water Engineering*, p. 413. Engineers Australia, Brisbane, 2011.

Jordan, P. W., K. Sih, P. I. Hill, N. Nandakumar, P. E. Weinmann, and R. J. Nathan. Areal reduction factors for estimation of design rainfall intensities for New South Wales and the Australian Capital Territory, In *Proceedings of the 34th World Congress of the International Association for Hydro-Environment Research and Engineering: 33rd Hydrology and Water Resources Symposium and 10th Conference on Hydraulics in Water Engineering*, p. 218. Engineers Australia, Brisbane, 2011.

Logan, N., C. Wiesenfeld, P. Jordan, B. Edwards, and R. Morden, Modelling the impact of stock and domestic farm dams in Queensland, *34th Hydrology and Water Resources Symposium*, Engineers Australia, Sydney, 2012.

Mannik, R., A. Boronkay, P. Jordan, T. Church, D. Hughes, S. Blockwell, Applying eWater Source as the catchment model for the Hawkesbury-Nepean Water Quality Model System, *34th Hydrology and Water Resources Symposium*, Engineers Australia, Sydney, 2012.

Wiesenfeld, C., N. Logan, A. Naseem, P. Jordan, B. Edwards, P. Delaney and R. Morden, Improving the inputs to assessing the impact of stock and domestic farm dams in

Queensland, *34th Hydrology and Water Resources Symposium*, Engineers Australia, Sydney, 2012.

Jordan, P., R. Mannik, A. Boronkay, T. Church, D. Hughes, eWater Source as the catchment model for the Hawkesbury-Nepean Water Quality Model System, *Proc. Conf. of New Zealand Hydrological Society*, Nelson, New Zealand, 2012.

Jordan, P., R. Nathan, L. Lowe, S. Lang and R. Morden, Setting sustainable diversion limits in unregulated catchments: The Australian experience, *Proc. Conf. of New Zealand Hydrological Society*, Nelson, New Zealand, 2012.

Jordan, P., Nathan, R., Hill, P., Raymond, M., Malone, T. and Kordomenidi, E., Stochastic Simulation of Inflow Hydrographs to Optimise Flood Mitigation Benefits Provided by Wivenhoe and Somerset Dams, *Proc. 35th Hydrology and Water Resources Symposium*, Engineers Australia, Perth, 2014.

Seed, A., Jordan, P., Pierce, C., Leonard, M., Nathan, R. and Kordomenidi, E. Stochastic simulation of space-time rainfall patterns for the Brisbane River catchment, *Proc. 35th Hydrology and Water Resources Symposium* Engineers Australia, Perth 2014.

Herron, A., Geoff, D., Jordan, P. and Blackmore, M., Customisations to Source to save time on large models and scenarios, *Proc. 35th Hydrology and Water Resources Symposium* Engineers Australia, Perth 2014.

Fowler, K., O'Connor, N., Jordan, P., Walter, N., Risk Assessment of Septic Tanks Using an Integrated Microbiological and Hydrological Modelling Framework, *Proc. International Conference on Peri-Urban Landscapes*, University of Western Sydney, Parramatta, 2014.

Jordan, P., Seed, A., Nathan, R., Hill, P., Kordomenidi, E., Pierce, C. and Leonard, M., Stochastic Simulation of Inflow Hydrographs for Wivenhoe and Somerset Dams, *Proc. Australian National Committee on Large Dams Annual Conference*, Canberra, 2014.

Cetin, L.T., Jordan, P.W., Conland, N., Sands, M., Cresswell, R., Herron, A., An integrated catchment modelling approach for exploring water allocation and nutrient limit setting policies, *Proc. 21st Century Watershed Technology Conference and Workshop Improving Water Quality and the Environment Conference*, Hamilton, New Zealand, November 2014.

Herron, A. and Jordan, P., Downscaling from regional climate model results into long term daily gridded surfaces for use in hydrological modelling, *Proc. Practical Responses to Climate Change Conference*, 2014.

Jordan, P., Nathan, R. and Seed, A. Application of spatial and space-time patterns of design rainfall to design flood estimation, *Proc. 36th Hydrology and Water Resources Symposium*, Engineers Australia, Hobart, 2015.

Jordan, P., Nathan, R. Weeks, W., Waskiw, P., Herron, A., Cetin, L., Rogencamp, G., Stephens, C., Russell, C. Estimation of flood risk for linear transport infrastructure using continuous simulation modelling, *Proc. 36th Hydrology and Water Resources Symposium*, Engineers Australia, Hobart, 2015.

Nathan, R., Scorah, M., Jordan, P., Lang, S., Kuczera, G., Schaefer, M., Weinmann, E., A tail of two models: Estimating the annual exceedance probability of probable maximum precipitation, *Proc. 36th Hydrology and Water Resources Symposium*, Engineers Australia, Hobart, 2015.

Jordan, P., O'Neil, C., Dallimore, C. and Yeates, P., Development of an in-stream processing model plugin for Nitrogen species, *Proc. eWater Source Conference*, Canberra, 24-25 August 2016.

Nathan, R., Stephens, D., Smith, M., Jordan, P., Scorah, M., Shepherd, D., Hill, P. and Syme, W., Impact of natural variability on design flood flows and levels, *Proc. New Zealand Hydrological Society and Engineers Australia Hydrology and Water Resources Symposium*, Queenstown, New Zealand, 2016.

Jordan, P., Rahman, J. and Conland, C., Building wider engagement through creative interfaces to water quality models developed in Source, *Proc. New Zealand Hydrological Society and Engineers Australia Hydrology and Water Resources Symposium*, Queenstown, New Zealand, 2016.

Jordan, P., Latu, K., Shepherd, D., Weeks, W., Nathan, R, Advances in continuous flood simulation for design of linear infrastructure, *Proc. Modelling and Simulation Society of Australia and New Zealand (MODSIM 2017)*, Hobart, 2017.

Jordan, P. and Scorah, M., Flood risk for linear infrastructure: A tool for incorporating climate change using eWater Source, *Proc. National Climate Change Adaptation Research Facility and Engineers Australia Climate Adaptation Conference*, 8-10 May 2018, Melbourne.

Beatty, R. and Jordan, P., Managing urban water demands: The challenges presented by climate change, *Proc. National Climate Change Adaptation Research Facility and Engineers Australia Climate Adaptation Conference*, 8-10 May 2018, Melbourne.

Jordan, P., J. Ahern, A. Northfield, W. Weeks, P. Jones, R. Nathan and C. Russell, Bruce Highway Link Flood Study, *Proc. Floodplain Management Australia Conference,* 29 May – 1 June 2018, Gold Coast.

Jordan, P., Quantifying uncertainty in nutrient load exports from diffuse landuses, Proc. 21st International RiverSymposium, 15-17 October 2018, Sydney.

Jordan, P., G. Race, R. Morden, D. Shepherd, S. Lang and R. Nathan, Trends in farm dam development over time in Victoria, 2000-2015, *Proc. Engineers Australia Hydrology and Water Resources Symposium*, 3-6 December 2018, Melbourne.

Jordan, P., and J. Eden, Bruce Highway Link Flood Study, *Proc. Engineers Australia Hydrology and Water Resources Symposium*, 3-6 December 2018, Melbourne.

Other reports or publications

Black, D., Wallbrink, P., Jordan, P., Waters, D., Carroll, C. and Blackmore, J., *Guidelines for Water Management Modelling: Towards Best-Practice Model Application*. eWater Cooperative Research Centre, 2011.

Vaze, J., Jordan, P., Beecham, R., Frost, A. and Summerell, G., *Guidelines for Rainfall-Runoff Modelling: Towards Best-Practice Model Application*. eWater Cooperative Research Centre, 2011.

Jordan, P., *Hydrological advice to commission of inquiry regarding 2010/11 Queensland floods, Assessment of impact of quarrying operations on flash flooding in Grantham on 10 January 2011*, 2011.

Jordan, P., *Hydrological advice to commission of inquiry regarding 2010/11 Queensland floods, Toowoomba and Lockyer Valley flash flood events of 10 and 11 January 2011*, Sinclair Knight Merz, 2011.

Jordan, P., Weinmann, E., and Hill, P. *Australian Rainfall and Runoff Revision Project 2: Collation and Review of Areal Reduction Factors*, Engineers Australia, 2013.

Jordan, P., *Witness Statement to Grantham Floods Commission of Inquiry*, 17 July 2015.

Jordan, P. *Response to Mr Cater's comments with regard to "Getting it Wrong on Grantham"*, Email to *Media Watch*, http://www.abc.net.au/mediawatch/transcripts/1538_jordan.pdf, 29 October 2015.

Jordan, P., Wrathall, M., Cresswell, R., Daniell, K., Springham, P.J., Glamore, W. and Herron, A. *Submission to the Senate Inquiry into Current and Future Impacts of Climate Change on Housing, Buildings and Infrastructure*, 2017.