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| *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**<br>Submitter |
| *And:* | **Waikato Regional Council**<br>Local Authority |

**STATEMENT OF EVIDENCE OF PHILLIP WILLIAM JORDAN**

**Block 2 Hearing Topics**

*Dated*: 3 May 2019

## STATEMENT OF EVIDENCE OF PHILLIP WILLIAM JORDAN

### SUMMARY

1 WPL developed a catchment scale model of the upper portion of the Waikato River catchment, referred to as the Ruahuwai Decision Support Tool (**RDST**). The RDST covers the spatial extent of the upper Waikato River catchment, between Taupo Gates and Lake Ohakuri. The RDST therefore covers the upper ten sub-catchments nominated in PC1, i.e. sub-catchment numbers 56, 58, 59, 62, 65, 66, 69, 72, 73 and 74 from Map 3.11-2 of PC1.

2 I have been engaged by WPL to undertake a peer review of the surface water and catchment modelling aspects of the RDST.

3 In my EIC for the Block 1 hearings, I articulated aspects of the Healthy Rivers Wai Ora (**HRWO**) modelling that were, in my view, not adequate in accurately capturing the hydrological and water quality response of the catchment. In my view, those deficiencies in modelling contaminants undermined the reliability of conclusions made using the modelling to support the argument that PC1 fulfils the requirements of the Resource Management Act (**RMA**). I have therefore compared and contrasted the performance of the RDST and the HRWO models for the upper Waikato catchment, to Lake Ohakuri. This EIC statement discusses the RDST and HRWO modelling.

4 The intent of the RDST was to create a catchment scale model of the upper Waikato River catchment, between Taupo Gates and Lake Ohakuri, which then allows WPL to "explore and understand the likely outcomes for land use options and to make informed mitigation decisions." (Mawer and Williamson, 2019, p. 1).[1] "The RDST enables the landowners to optimise land value and utilisation through an adaptive management approach without compromising environmental outcomes and risking stranded assets." (Mawer and Williamson, 2019, p. 1). The RDST was run to demonstrate scenarios for land management and mitigation on the Wairakei Estate that produce compliance with the 10 and 80-year targets for in-stream attributes (or freshwater objectives) expressed in Table 3.11-1 of PC1.

5 It was therefore a requirement that the RDST produces sufficiently accurate and reliable predictions of in-stream water quality attributes for the land management and mitigation scenarios that were tested within the RDST. The RDST was developed and calibrated in a manner that addressed the shortcomings that I had identified in the

[1] Mawer, J. and Williamson, J. (2019) *Ruahuwai Integrated Catchment Modelling Project, Volume 1 - RDST Overview and Scenarios*, Revision 3, 30 April 2019. Consultancy report prepared for Wairakei Pastoral Limited.

HRWO modelling. In my EIC for Block 1, I also pointed out the shortcomings of applying the steady-state HRWO model to predict concentrations and loads of TN, TP and E. coli. The RDST is a dynamic model, which explicitly models rainfall, runoff, surface and groundwater processes and contaminant loads and concentrations on a daily time step.

6 The RDST was run using daily climatic data inputs for the period from 1 January 1972 to 30 June 2018. For the calibration run, the RDST was run with land use that changed over four different periods. The calibration run of the RDST therefore included the dynamic changes in land use over time across the model domain.

7 As discussed above, supported by the documentation presented in Mawer et al. (2019)[2], the RDST reproduced the temporal dynamics of flow, TN, TP, TSS and E. coli concentrations that were observed in monitoring data across several decades of available data collection.

8 The RDST was capturing the temporal variations well at the majority of the monitoring sites, including higher TN concentrations during surface runoff events, seasonal variations in TN concentration associated with seasonal variations in groundwater discharge and, for several sites, gradual increase in TN associated with land use change. For the ten monitoring sites in the upper Waikato catchment (RDST model domain), the RDST produced a similar level of accuracy in predicting mean annual TN loads for the 2010-2014 period to the HRWO model.

9 The RDST also predicted the variability in TP and TSS concentrations seen in monitoring data at the majority of monitoring sites, including higher concentrations during surface runoff events. For the ten monitoring sites in the upper Waikato catchment (RDST model domain), the RDST produced a similar level of accuracy in predicting mean annual TP loads for the 2010-2014 period to the HRWO model.

10 Neither the RDST nor the HRWO models produced particularly accurate calibrations to E. coli loads over this period. However, the RDST produced reasonable estimates of the 95$^{th}$ percentile E. coli concentrations across the nine monitoring sites in the upper catchment where HRWO had calculated monitored E. coli loads.

11 The RDST is dynamic model, which was calibrated to all of the available streamflow gauging and water quality monitoring data. At several sites, the monitoring data extends from 1993 to 2018. The parameter values in the RDST were therefore calibrated to water quality monitoring data collected over the full data collection period

[2] Mawer, J., Loft, J., and Williamson, J. (2019) Ruahuwai Integrated Catchment Modelling Project, Volume 4 - SOURCE Catchment Modelling Report, Revision 4, 30 April 2019. Consultancy report prepared for Wairakei Pastoral Limited.

and were not limited to the 2010-2014 period only. As the RDST models the temporal dynamics of the system, it may be run to reliably predict the influences of changes in land use, land management and mitigation actions, without the concern that parameter values adopted in the RDST were particularly tuned to the climatic conditions that occurred over the relatively dry HRWO/PC1 2010-2014 baseline period. The RDST possessed an advantage over the HRWO model in this respect, as the parameters of the HRWO model may be biased by the selection of the baseline period adopted for calibration.

12 The RDST produced a mean annual load of TN that was very similar to the mean annual load from the HRWO model and which fitted within the range of mean annual loads estimated from boot-strapping analysis on the monitored TN and flow data. The RDST produced conservative estimates for the TP and E. coli mean annual loads over the 2010-14 period at Ohakuri Tailrace, when compared with the monitoring data. Because the RDST produced load and concentration estimates at the downstream extent of the upper catchment, Ohakuri Tailrace, that were either well matched to the monitoring data or conservative (high) estimates, it would be possible to use the outputs from the RDST at Ohakuri Tailrace to predict changes in outcomes for constituent loads and concentrations at sites on the Waikato River downstream of Lake Ohakuri.

13 The RDST has demonstrated that it is possible to model contaminant concentrations and loads for a sub-catchment arrangement with a finer spatial resolution than would be determined from the monitoring network. The RDST was modelled as 415 individual sub-catchments. Sub-catchment boundaries were delineated on the basis of the terrain and surface water drainage network and other physical characteristics that could influence the overall hydrological response of the catchment, such as variations in slope, soil type, geology or vegetation cover. For the RDST, the sub-catchments represented the spatial unit that was used for calculation of flows, subsurface drainage and contaminant loads and concentrations.

14 Sound hydrological and ecological reasons were presented by Mr Williamson and Dr Neale in Block 1 to separate sub-catchment 66 of PC1 into sub-catchments 66A and 66B, and the RDST now provides the ability to set water quality objectives at the intersection between the two new sub-catchments.

15 The RDST has currently been calibrated to provide estimates of concentrations and loads for the four contaminants that are addressed explicitly in PC1, TN, TP, TSS and E. coli. The computational framework of the RDST is sufficiently flexible that additional constituents could be included at some later time.

## BLOCK 2 HEARING TOPICS

1 My name is **Phillip William Jordan**. I have the qualifications and experience recorded in my statement of evidence filed in relation to the Block 1 Hearing Topics.

2 My statement of evidence (**EIC**) has been prepared in accordance with the Code of Conduct for Expert Witnesses set out in Section 7 of the Environment Court of New Zealand Practice Note 2014.

### PART C – TOPICS

### TOPIC C1. DIFFUSE DISCHARGE MANAGEMENT

#### RDST and scenario modelling

***Purpose of RDST***

3 Wairakei Pastoral Limited (**WPL**) developed a catchment scale model of the upper portion of the Waikato River catchment, referred to as the Ruahuwai Decision Support Tool (**RDST**). The RDST covers the spatial extent of the upper Waikato River catchment, between Taupo Gates and Lake Ohakuri. The RDST therefore covers the upper ten sub-catchments nominated in Plan Change 1 (**PC1**), i.e. sub-catchment numbers 56, 58, 59, 62, 65, 66, 69, 72, 73 and 74 from Map 3.11-2 of PC1.

4 I have been engaged by WPL to undertake a peer review of the surface water and catchment modelling aspects of the RDST. In my EIC and rebuttal evidence for the Block 1 hearing, expressed several concerns that I had about the underlying science and modelling that was used in preparing PC1, as expressed in the the Healthy Rivers Wai Ora (**HRWO**) modelling. I have therefore compared and contrasted the performance of the RDST and the HRWO models for the upper Waikato catchment, to Lake Ohakuri. This EIC statement discusses the RDST and HRWO modelling.

5 Modelling undertaken using the RDST is documented in Mawer and Williamson (2019), Mawer et al. (2019), Zhao et al. (2019a)[3] and Zhao et al. (2019b)[4]. The intent of the RDST was to create a catchment scale model of the upper Waikato River catchment, between Taupo Gates and Lake Ohakuri, which then allows WPL to "explore and understand the likely outcomes for land use options and

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[3] Zhao, H., Williamson, J., and Walton, M. (2019a) *Ruahuwai Integrated Catchment Modelling Project, Volume 2 – APSIM Modelling Report*, Revision 2, 30 April 2019. Consultancy report prepared for Wairakei Pastoral Limited.

[4] Zhao, H., Williamson, J., Kalbus, E., and Burgess, R. (2019b) *Ruahuwai Integrated Catchment Modelling Project, Volume 3 – MODFLOW Groundwater Modelling Report*, Revision 11, 30 April 2019. Consultancy report prepared for Wairakei Pastoral Limited.

to make informed mitigation decisions." (Mawer and Williamson, 2019, p. 1).

6 "The RDST enables the landowners to optimise land value and utilisation through an adaptive management approach without compromising environmental outcomes and risking stranded assets." (Mawer and Williamson, 2019, p. 1). The RDST was run to demonstrate scenarios for land management and mitigation on the Wairakei Estate (**the Estate**) that produce compliance with the 10 and 80-year targets for in-stream attributes (or freshwater objectives) expressed in Table 3.11-1 of PC1.

7 It was therefore a requirement that the RDST should produce sufficiently accurate and reliable predictions of in-stream water quality attributes for the land management and mitigation scenarios that were tested within the RDST. In my view, this test would be satisfied if the RDST produces model predictions for the four contaminants managed in PC1, i.e. total suspended sediment (**TSS**), total nitrogen (**TN**), total phosphorus (**TP**) and Escherichia coli (**E. coli**), that are at least equivalent in reliability and accuracy to those produced by the HRWO model for the Ruahuwai sub-catchment.

8 In addition, there was a requirement that the RDST should not be subject to the same deficiencies that I identified with the HRWO model, as expressed in my EIC and rebuttal evidence for the Block 1 hearing. In my EIC for the Block 1 Hearing Topics, I summarised several concerns that I had about the underlying science and modelling that was used in preparing PC1, as follows:

8.1 *"Aspects of the hydrological and water quality modelling that are not adequate in accurately capturing the hydrological and water quality response of the catchment;*

8.2 *The modelling approach adopted, including the use of CLUES, includes considerable uncertainty;*

8.3 *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;*

8.4 *Deficiencies in modelling contaminants undermine the reliability of the conclusions made;*

8.5 *The sub-catchment delineation was determined by limitations in the modelling approach and method of analysis adopted."*

9 Figure 1 demonstrates the inter-annual variability in rainfall for the Estate. Daily data was obtained from NIWA for Virtual Climate Station Network location 29983, which is located within the Estate at 38.675° South latitude and 176.275° East longitude. The data analysis shows that for this location, the 2010-2014 period was drier than the long-term climatic mean, calculated over 1972-2018. The annual rainfall total for 2010-2014 was 15% less than the long-term mean.

10 Leaching of TN and discharge of TP occurs at higher rates when soils are saturated, which is more likely to occur over the winter and early spring period. The lower panel in Figure 1 shows that the total rainfall for June-November for the 2010-2014 was 21% less than the long-term mean for all June-November periods. In-fact, the 2010-2014 period had the lowest rolling five-year average for June-November rainfall of all 43 possible five-year periods in the 1972-2018 period.

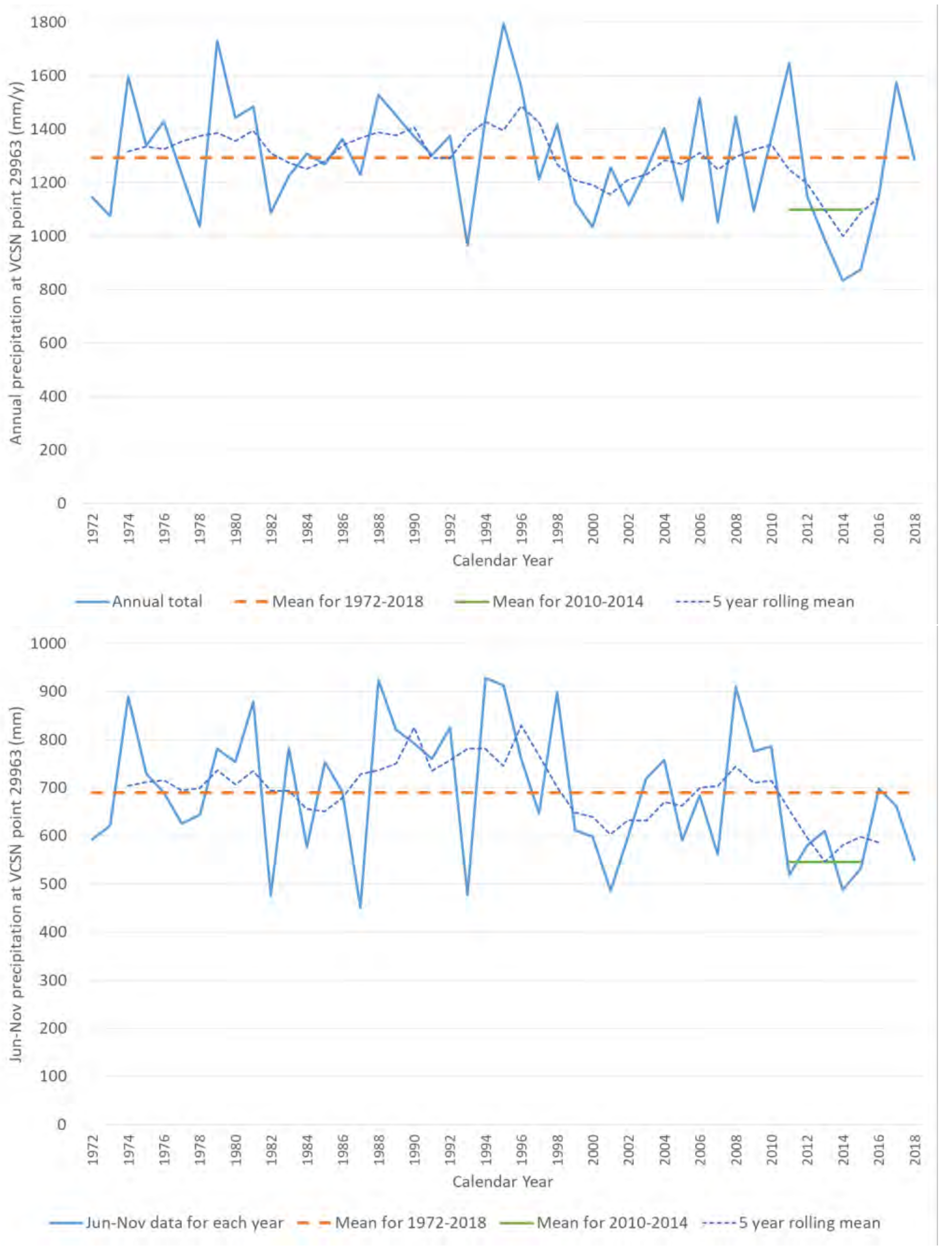


*Figure 1 Mean precipitation by year, 1972-2018, for whole calendar year (top panel) and June to November of each year (bottom panel) for Virtual Climate Station Site at 38.675°S, 176.275°E, within the Estate*

11 In my EIC for Block 1, I pointed out the shortcomings of applying the steady-state HRWO model to predict concentrations and loads of TN, TP and E. coli. The RDST is a dynamic model, which explicitly models rainfall, runoff, surface and groundwater processes and contaminant loads and concentrations on a daily time step. I will discuss later in my EIC how the temporal dynamics represented in the RDST make it superior to the steady state HRWO model for

producing reliable predictions of contaminant loads and concentrations.

***Delineation of sub-catchments***

12 In my EIC, I noted that the delineation of sub-catchments for the HRWO model, which was 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”.

13 By contrast, the RDST was modelled as 415 individual sub-catchments. Sub-catchment boundaries were delineated on the basis of the terrain and surface water drainage network and other physical characteristics that could influence the overall hydrological response of the catchment, such as variations in slope, soil type, geology or vegetation cover. For the RDST, the sub-catchments represented the spatial unit that was used for calculation of flows, subsurface drainage and contaminant loads and concentrations.

14 Monitoring data was only available at the outlet of a small proportion of the modelling sub-catchments that were used for the RDST. Although model results may be examined at the outlet of any of the 415 model sub-catchments, the reliability and accuracy of the RDST may only be assessed objectively at the subset of locations where sufficient monitored flow and contaminant load and concentration data is available.

15 In paragraph 34 of Dr Neale’s EIC for Block 1, he argues that, “from an appearance and an ecological function perspective, the Waikato River can be considered to change from a riverine system to a lacustrine system between the Ohaaki and Ohakuri Tailrace monitoring sites. Analysis of the river in this area indicates that change occurs around Tutukau Bridge and therefore following the logic in PC1, it would be appropriate to manage the river upstream and downstream of this location differently” (Neale, 2019, para. 34).[5] It would therefore be appropriate to split the current sub-catchment 66 of PC1 into sub-catchments 66A and 66B at Tutukau Bridge.

16 The RDST has demonstrated that it is possible to model contaminant concentrations and loads for a sub-catchment arrangement with a finer spatial resolution than would be determined from the monitoring network. If the RDST is accepted, it would therefore be possible to set water quality objectives at the intersection between the two new sub-catchments 66A and 66B.

[5] Neale, M. (2019) Statement of evidence of Martin William Neale, Block 1 Hearing Topics, 15 February 2019.

17 WPL contracted Jacobs to collect and analyse water quality monitoring data at site RQ01, which is located approximately 300 m downstream of the proposed subdivision between sub-catchments 66A and 66B. Samples were collected at RQ01 between 2005 and 2011, with 25 samples collected for each of TN, TP and E. coli and 18 samples for TSS. Concentrations of TN, TP, TSS and E. coli were compared between the RDST calibration run and the monitoring data collected at this site. Table 1 presents comparisons between statistics computed for the contaminant concentrations at site RQ1 and statistics calculated from the RDST calibration run, which were extracted from the tables in Appendix E of Mawer et al. (2019). The RDST could therefore (as noted above) be used to set objectives at the proposed new boundary between sub-catchments 66A and 66B.

*Table 1 Comparisons between statistics of monitored concentrations and concentrations from the calibration run of the RDST for TN, TP, TSS and E. coli for the Waikato River at site RQ01*

| Contaminant | Statistic | Monitored data | RDST calibration model |
|---|---|---|---|
| **TN** | Mean concentration | 0.28 mg/L | 0.22 mg/L |
| **TN** | 5th percentile concentration | 0.10 mg/L | 0.12 mg/L |
| **TN** | Median concentration | 0.20 mg/L | 0.20 mg/L |
| **TN** | 95th percentile concentration | 0.74 mg/L | 0.31 mg/L |
| **TP** | Mean concentration | 0.031 mg/L | 0.025 mg/L |
| **TP** | 5th percentile concentration | 0.015 mg/L | 0.013 mg/L |
| **TP** | Median concentration | 0.028 mg/L | 0.018 mg/L |
| **TP** | 95th percentile concentration | 0.051 mg/L | 0.040 mg/L |
| **E. coli** | Mean concentration | 54 cfu/100 mL | 23 cfu/100 mL |
| **E. coli** | 5th percentile concentration | 9 cfu/100 mL | 4 cfu/100 mL |
| **E. coli** | Median concentration | 31 cfu/100 mL | 9 cfu/100 mL |
| **E. coli** | 95th percentile concentration | 102 cfu/100 mL | 57 cfu/100 mL |
| **TSS** | Mean concentration | 4.0 mg/L | 3.5 mg/L |
| **TSS** | 5th percentile concentration | 2.9 mg/L | 2.2 mg/L |
| **TSS** | Median concentration | 3.0 mg/L | 2.4 mg/L |
| **TSS** | 95th percentile concentration | 7.5 mg/L | 7.9 mg/L |

***Modelling of runoff, streamflow and groundwater in RDST***

18 The RDST was run using daily climatic data inputs for the period from 1 January 1972 to 30 June 2018. For the calibration run, the RDST was run with land use that changed over four different periods:

a) For 1 January 1972 to 31 December 2004, the RDST was run with land use data imported from Agribase as at 2000;

b) For 1 January 2005 to 31 December 2009, the RDST was run with land use data imported from Agribase as at 2005;

c) For 1 January 2010 to 31 December 2014, the RDST was run with land use data imported from Agribase as at 2010;

d) For 1 January 2015 to 30 June 2018, the RDST was run with land use data imported from Agribase as at 2015 for areas outside the Estate but updated with WPL's documented land use for those areas inside the Estate.

19 The calibration run of the RDST therefore included the dynamic changes in land use over time across the model domain.

20 The RDST used the Soil Moisture Water Balance Model with Vadose Zone (**SMWBM_VZ**) to perform a daily simulation of surface runoff and drainage to groundwater. SMWBM_VZ was implemented within the eWater Source modelling framework. A full description of SMWBM_VZ is provided in Mawer et al. (2019). SMWBM_VZ accounts for rainfall intercepted by vegetation, infiltration into the soil profile, surface ponding, evaporation from vegetation, soil and surface ponded water, drainage from the root zone into the remainder of the vadose zone, drainage through the vadose zone to groundwater and surface runoff. Source runs SMWBM_VZ in each of the 415 sub-catchments across the RDST domain, to generate a daily time series of drainage to groundwater and surface runoff for each of the 415 model sub-catchments.

21 For the RDST, a MODFLOW model was developed utilising the MODFLOW-2005 (Harbaugh, 2005)[6] numerical groundwater flow code in the GMS v10.2 graphical user interface. Details on the groundwater model in the RDST are provided in Zhao et al. (2019b). The horizontal spatial resolution of the groundwater flow model was 300 m. The model was run for the period between 1 January 1972 and 30 June 2018, a period of 46½ years. "Given that the response time over the vast majority of the regional groundwater system is significantly delayed compared to the surficial processes that govern them. To reduce this, but still capture important precipitation fluxes, a variable stress period was utilised." (Zhao et al., 2019b). Drainage to the groundwater model from Source was averaged over 287 periods, where each period had varying duration of between 7 and 295 days. The start and end dates of the periods were selected to represent periods of appreciable change in surface drainage,

[6] Harbaugh, A.W. (2005). Modflow 2005. The U.S. Geological Survey Modular Ground-water Model – The Groundwater Flow Process. U.S. Geological Survey Techniques and Methods 6-A16.

particularly to discriminate extended wet periods and large storm events from drier periods (Zhao et al., 2019b).

22 Drain boundary conditions were used to simulate perennial streams in the MODFLOW model (Zhao et al., 2019b). Outflows were calculated at these locations from the MODFLOW model, which were then input to the Source model as groundwater inputs. The MODFLOW model was therefore used to represent groundwater flow pathways within the RDST, with SMWBM_VZ used to represent surface runoff generation and percolation into groundwater.

23 The MODFLOW model was calibrated against monitored levels in groundwater bores and gauged flows in surface water streams. Ground water modelling is outside of my area of expertise, so I cannot provide an expert opinion on the calibration of the groundwater modelling. However, I note that Mr Williamson details in Table 1 of his evidence the peer review carried out regarding the MODFLOW / MT3DMS model (and other models) in relation to development of the RDST.

24 The RDST was used to simulate daily flows. These were compared to gauged flows at several locations where streamflow gauging data was available across the model domain. The RDST accurately simulated the daily flow duration curve at the following locations:

a) Waikato River at Ohaaki Bridge;

b) Waikato River at Ohakuri Tailrace;

c) Waiotapu River at Campbells Road;

d) Waiotapu River at Reporoa;

e) Pueto Stream at WPL;

f) Orakanui Stream at Jacobs;

g) Otamakokore Stream at Hossack Road.

25 Daily flow duration curves from gauged data and modelled data were documented in Section 6.2 of Mawer et al. (2019). The performance of the flow model calibration across seven gauging sites in the RDST domain is summarised in Figure 2. As shown on the figure, the RDST produced an excellent calibration to gauged median, 5$^{th}$ and 95$^{th}$ percentile daily flows at all sites where more than 100 observations of daily streamflow data was available.

26 The RDST reproduced the daily temporal dynamics of the flows. This was assessed by comparing time series of modelled flows from the calibration scenario against the time series of gauged streamflow at several sites. The model also produced good matches to the time

series of flows for several additional sites that had intermittent “spot gauging” data (observations for less than 100 days), as shown by the time series plots in Section 6.2 of Mawer et al. (2019).

27 Unlike the RDST, the HRWO model did not simulate flows. It was therefore not possible to compare the relative accuracy of each model in simulating in-stream flows.

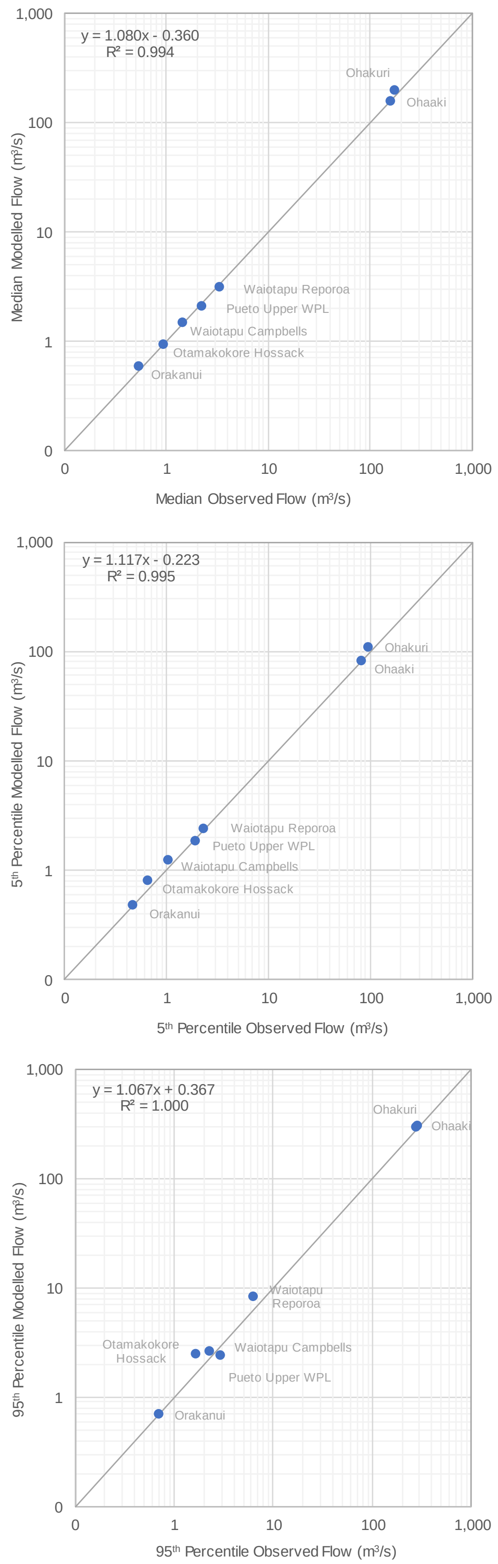


*Figure 2 Scatter plot of observed and modelled daily flows, for flows with 50% probability of exceedance, 5% probability of exceeedance and 95% probability of exceedance*

***Modelling of TN in RDST***

28 The concentration of TN in groundwater was modelled using the mass transport code MT3DMS v. 5.3 (Zheng, 2010)[7]. "MT3DMS is a 3-D modular transport model for simulating transport processes such as advection, dispersion, diffusion, and chemical reactions in the groundwater flow systems" (Zhao et al., 2019b). Denitrification in the groundwater was modelled within MT3DMS, as detailed in Zhao et al. (2019b).

29 APSIM models were run for each of the land uses across the RDST, in order to simulate daily loads of TN leached to groundwater across each of the land uses in the model domain (Zhao et al., 2019,). Temporal variations in TN load leached to the groundwater were therefore simulated due to the combined influences of (a) daily variations in climate between 1972 and 2018, (b) variations in TN leaching rate associated with the changing land use across the four land use periods, as set out in para. 18 above. The spatial and temporal variations in average annual TN loading over the calibration period represented in the model were summarised in the maps shown in Figure 26 of Zhao et al. (2019).

30 Figure 3, reproduced from Mawer et al. (2019) shows the time series of TN concentrations in the Pueto Stream at Broadlands produced by the RDST for the calibration run and comparison with in-stream TN monitoring at this location. The time series shows that the RDST represents day-to-day variations in concentrations associated with both surface runoff events and seasonal to annual variations in groundwater discharge. Figure 3 also demonstrates that the RDST produced a good representation of the temporal trend of increasing TN concentration in the Pueto stream between 1993 and 2018.

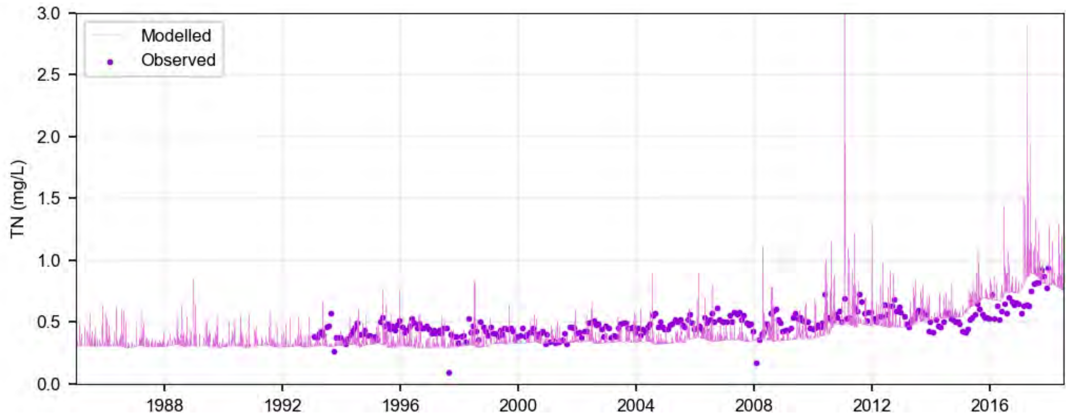


*Figure 3 Comparison of measured TN concentration and modelled TN concentration from the RDST calibration run for Pueto Stream at Broadlands (Figure 13 in Appendix E of Mawer et al., 2019)*

[7] Zheng, C., 2010, MT3DMS v5.3 Supplemental User's Guide, Technical Report to the U.S. Army Engineer Research and Development Center, Department of Geological Sciences, University of Alabama, 51 p

31 Plots of time series in TN concentration from the RDST, shown in Appendix E of Mawer et al. (2019), also demonstrated that the RDST was capturing the temporal variations well at the majority of the monitoring sites, including higher TN concentrations during surface runoff events, seasonal variations in TN concentration associated with seasonal variations in groundwater discharge and, for several sites, gradual increase in TN associated with land use change.

32 Figure 4 compares the performance of the RDST and HRWO models in calculating mean annual loads of TN, for the ten monitoring sites across the Ruahuwai domain over the 2010-2014 period. The plot shows that the RDST produced a similar level of accuracy in calibration to the HRWO model for these sites. On average, the RDST made slightly conservative (high) predictions of TN load, whereas the HRWO model was slightly non-conservative (low). It is likely that this was because the HRWO model was calibrated to TN loads for all of the monitoring sites across the Waikato catchment and the calibration was not necessarily specifically targeted to the upper catchment.

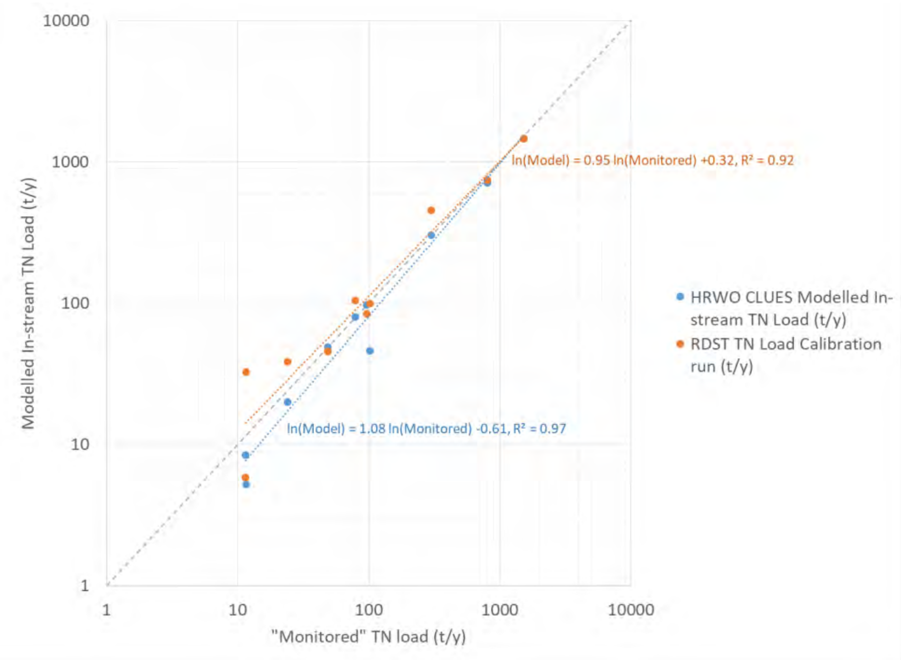


*Figure 4 Scatter plots of observed mean annual TN loads computed over period 1 January 2010 to 31 December 2014, compared with mean annual TN loads calculated by the HRWO model (blue) and the RDST calibration model (orange) over the same period*

33 The structure of the RDST was capable of representing both spatial and temporal variations in TN concentrations and loads. The HRWO model was a steady state model and therefore did not explicitly represent any temporal variations in TN loads or concentrations.

34 In my EIC for Block 1, I pointed out the shortcomings of applying the steady-state HRWO model to predict concentrations and loads of TN, TP and E. coli. Semadeni-Davies et al. (2016)[8] 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. 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.

35 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.

36 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.

37 In contrast to the steady-state HRWO model, the RDST explicitly represents the increase in TN loads and concentrations that has occurred over recent years, associated with land use change, in a manner that is consistent with the trend in monitored concentrations.

38 The RDST also represents stored TN within the groundwater. For representation of future scenarios, the groundwater model within the RDST can therefore be initialised with TN concentrations and then the simulations can be run forward in time with a continuation of a particular set of land use and mitigation actions across the model domain and repetition of historical climatic conditions. In simulations of future conditions, the RDST therefore explicitly simulates the residual load of TN that is currently in the groundwater due to past land use change. The trajectory of the trends in TN concentration was compared to monitored in-stream TN concentrations.

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8 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

***Modelling of TP in RDST***

39 Figure 5, reproduced from Mawer et al. (2019) shows the time series of TP concentrations in the Pueto Stream at Broadlands produced by the RDST for the calibration run and comparison with in-stream TP monitoring at this location. The time series shows that the RDST represents day-to-day variations in concentrations associated with both surface runoff events and seasonal to annual variations in discharge from saturated or near-saturated soil within the catchment.

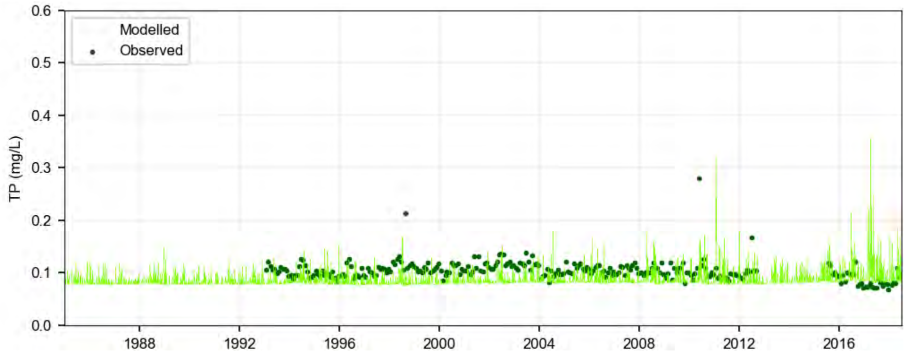


*Figure 5 Comparison of measured TP concentration and modelled TP concentration from the RDST calibration run for Pueto Stream at Broadlands (Figure 40 in Appendix E of Mawer et al., 2019)*

40 Plots of time series in TP concentration from the RDST, shown in Appendix E of Mawer et al. (2019), also demonstrated that the RDST was capturing the temporal variations well at the majority of the monitoring sites, including higher TP concentrations during surface runoff events, seasonal variations in TP concentration associated with seasonal variations in groundwater discharge and, for several sites, gradual increase in TP associated with land use change.

41 Figure 6 compares the performance of the RDST and HRWO models in calculating mean annual loads of TP, for the ten monitoring sites across the Ruahuwai domain over the 2010-2014 period. The plot shows that the RDST produced a similar level of accuracy in calibration to the HRWO model for these sites. On average, the RDST made slightly conservative (high) predictions of TP load, whereas the HRWO model was slightly non-conservative (low). It is likely that this was because the HRWO model was calibrated to TP loads for all of the monitoring sites across the Waikato catchment and the calibration was not necessarily specifically targeted to the upper catchment.

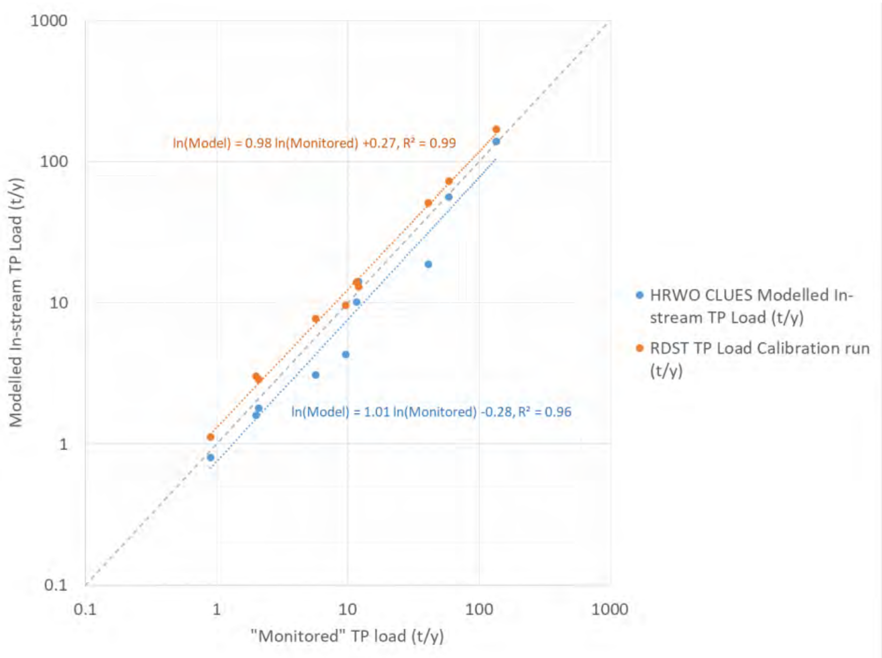


*Figure 6 Scatter plots of observed mean annual TP loads computed over period 1 January 2010 to 31 December 2014, compared with mean annual TP loads calculated by the HRWO model (blue) and the RDST calibration model (orange) over the same period*

***Modelling of TSS in RDST***

42 Figure 7, reproduced from Mawer et al. (2019) shows the time series of TSS concentrations in the Pueto Stream at SW10 produced by the RDST for the calibration run and comparison with in-stream TSS monitoring at this location. The time series shows that the RDST represents day-to-day variations in concentrations associated with surface runoff events.

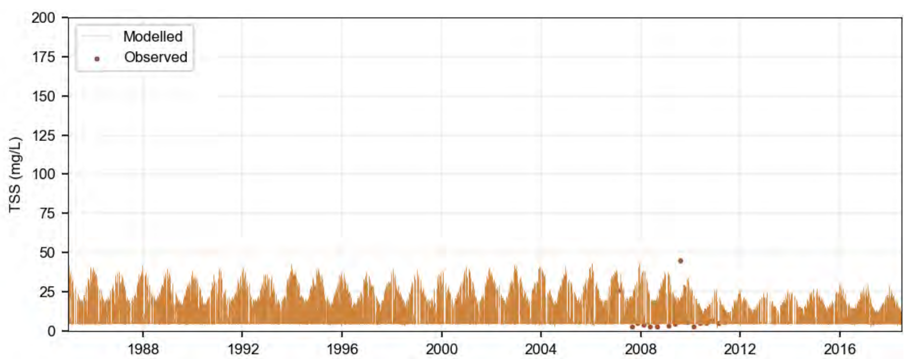


*Figure 7 Comparison of measured TSS concentration and modelled TSS concentration from the RDST calibration run for Pueto Stream at SW10 (Figure 60 in Appendix E of Mawer et al., 2019)*

43 Plots of time series in TSS concentration from the RDST, shown in Appendix E of Mawer et al. (2019), also demonstrated that the RDST was capturing the temporal variations in TSS at the majority of the

monitoring sites, including higher TSS concentrations during surface runoff events.

44 There were only three sites in the model domain that had sufficient data over the 2010-2014 period to permit comparison of TSS loads. It was therefore not appropriate to make a meaningful comparison of the performance of the HRWO and RDST in simulation of TSS loads or concentrations. Figures 67 and 68 of Mawer et al. (2019) demonstrate that for the three sites that had sufficient data for comparison, the RDST calibration scenario made accurate and reliable predictions of the mean and 95$^{th}$ percentile TSS concentrations.

***Modelling of E. coli in RDST***

45 Figure 8, reproduced from Mawer et al. (2019) shows the time series of E. coli concentrations in the Pueto Stream at Broadlands produced by the RDST for the calibration run and comparison with in-stream E. coli monitoring at this location. The time series shows that the RDST represents day-to-day variations in concentrations associated with surface runoff events.

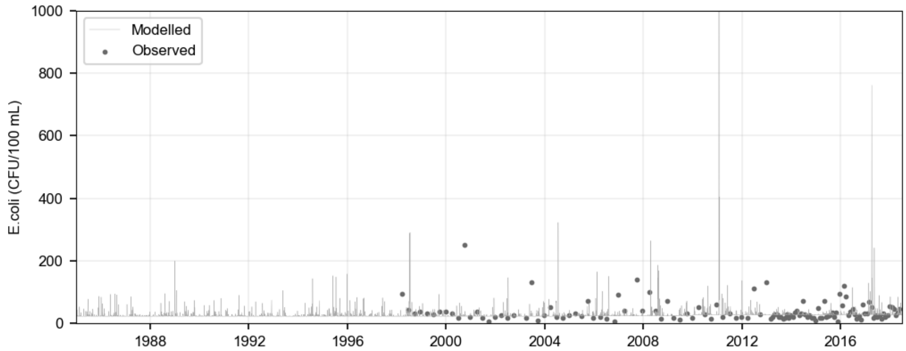


*Figure 8 Comparison of measured E. coli concentration and modelled E. coli concentration from the RDST calibration run for Pueto Stream at Broadlands SW10 (Figure 86 in Appendix E of Mawer et al., 2019)*

46 Plots of time series in E. coli concentration from the RDST, shown in Appendix E of Mawer et al. (2019), also demonstrated that the RDST was capturing the temporal variations well at the majority of the monitoring sites, including higher E. coli concentrations during surface runoff events.

47 Figure 9 compares the performance of the RDST and HRWO models in calculating mean annual loads of E. coli, for the nine monitoring sites across the Ruahuwai domain over the 2010-2014 period. Neither the RDST nor the HRWO models produced particularly accurate calibrations to E. coli loads over this period. There was considerable uncertainty in the "monitored" E. coli loads because monitoring of E. coli concentrations occurs only once per month and E. coli concentrations typically demonstrate very large temporal variability. Therefore, very considerable uncertainty is introduced by

interpolating how the E. coli concentrations had varied temporally during the periods between monitoring. This increases the relative uncertainty in the monitored E. coli loads, when compared with loads estimated from monitoring data for TN, TP and TSS. Figure 9 shows that on average, the RDST made more conservative (high) estimates of the mean annual E. coli load the HRWO model.

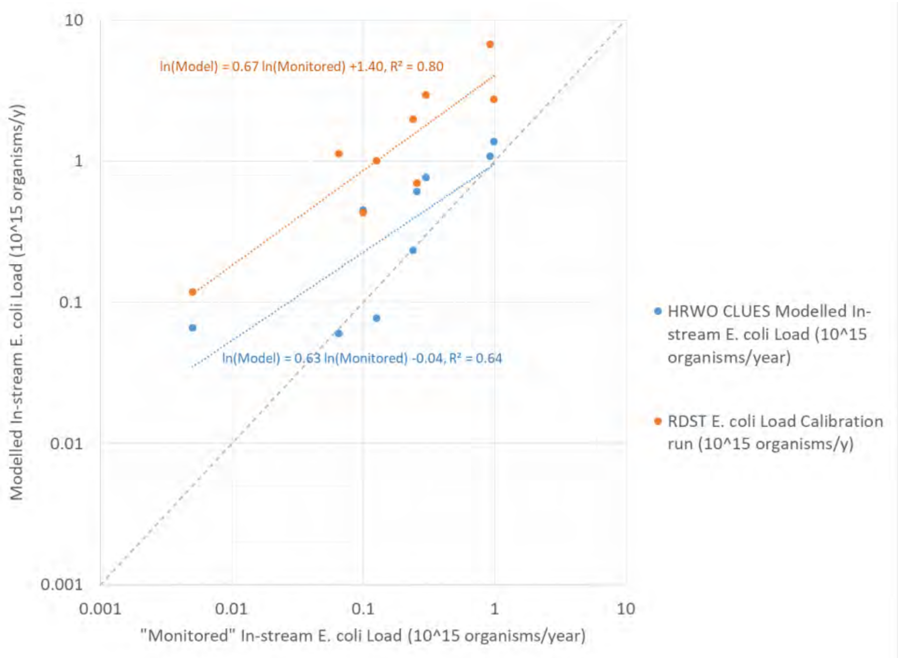


*Figure 9 Scatter plots of observed mean annual E. coli loads computed over period 1 January 2010 to 31 December 2014, compared with mean annual E. coli loads calculated by the HRWO model (blue) and the RDST calibration model (orange) over the same period*

48 Figure 10 (reproduced from Figure 74 in Mawer et al., 2019) compares the performance of the RDST model in calculating 95$^{th}$ percentile concentrations of E. coli, for the nine monitoring sites across the Ruahuwai domain over the 2010-2014 period. Given the temporal variability in E. coli concentrations that is typically observed, the RDST is producing reasonable estimates of the 95$^{th}$ percentile E. coli concentrations across the nine monitoring sites. Although Figure 9 showed that the RDST was over-predicting loads of E. coli, on average, Figure 10 shows that the RDST is producing more accurate simulations of 95$^{th}$ percentile concentration, with underprediction at about half of the monitoring sites.

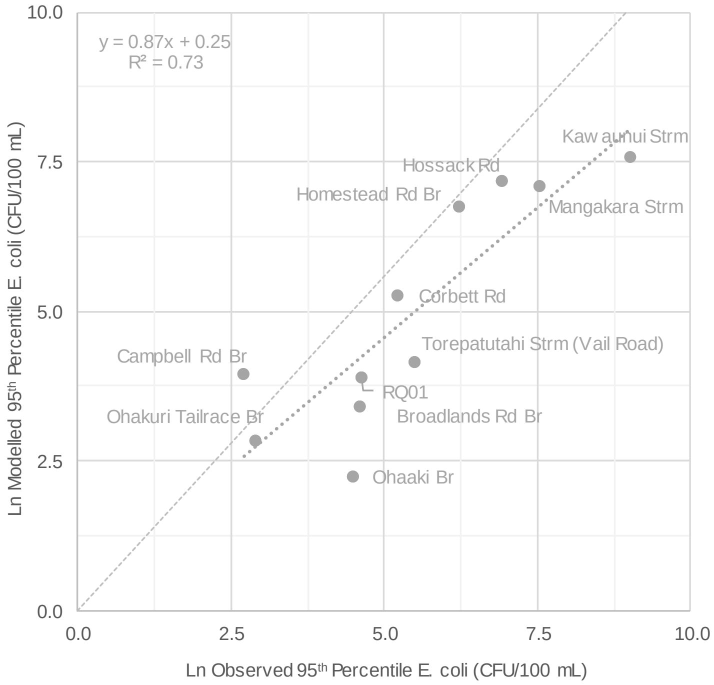


*Figure 10 Scatter plots of observed 95th percentile E. coli concentrations over the full period of monitoring data available at each site, compared with 95th percentile E. coli concentrations calculated by the HRWO model (blue) and the RDST calibration model (orange) (Figure 77 in Mawer et al., 2019)*

***Influence of baseline 2010-2014 monitoring period on model results***

49 Dr Neale's EIC for Block 1 explained that the drier than average conditions over the 2010-2014 period may have underestimated the true state of contaminant concentrations and loads than would have been computed over a period that represented long-term average climate conditions. I therefore pointed out in my EIC for Block 1 that, "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." I then went on to explain in my Block 1 EIC that, "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" (para 20).

50 The RDST is a dynamic model, which was calibrated to all of the available streamflow gauging and water quality monitoring data. At

several sites, the monitoring data extends from 1993 to 2018. Mawer et al. (2019) demonstrated that the RDST captures the seasonal variations and annual trends in the water quality monitoring data across this period. Example plots of time series of contaminant concentrations at sites in the Pueto Stream have been presented above to also demonstrate this.

51 The parameter values in the RDST were therefore calibrated to water quality monitoring data collected over the full data collection period and were not limited to the 2010-2014 period only. It is therefore unlikely that the parameter values in the RDST were biased toward matching the 2010-2014 period, although the scatter plots shown above demonstrate that for most contaminants, the RDST produced a similar level of ability to accurately predict loads and concentrations for the 2010-2014 period to the HRWO model. As the RDST models the temporal dynamics of the system, it may be run to reliably predict the influences of changes in land use, land management and mitigation actions, without the concern that parameter values adopted in the RDST were particularly tuned to the climatic conditions that occurred over the 2010-2014 baseline period.

***Uncertainty analysis***

52 In his EIC for the Block 1 hearings, Dr Cox stated that, "Despite noted significant uncertainties in many of the key model parameters, the (HRWO) models are not supported by uncertainty or sensitivity analyses of any sort. Consequently, the robustness of the (HRWO) model calibration and predictive power is unknown. This impacts (HRWO) model credibility and acceptance among stakeholders" (Cox, 2019, paragraph 18).[9]

53 An uncertainty analysis is currently being undertaken for the RDST to address any parallel concerns to the HRWO models about lack of understanding of uncertainty or sensitivity of the RDST model predictions to input data and parameterisation. Results from the uncertainty analysis were not completed in time for filing of EIC for Block 2. However, my understanding is that the uncertainty analysis will be available in time for the Block 3 hearings.

***Influence of changes in loads at Ohakuri Tailrace on contaminant loads and concentrations downstream***

54 The RDST is a sub-catchment level model, which predicts concentrations and loads only as far downstream as Ohakuri Tailrace. Table 2 shows the comparisons between mean annual loads of TN, TP and E. coli from the RDST and the HRWO model at Ohakuri Tailrace with monitored loads (see Tables G-1 and G-2 of Semadini Davies et al., 2016[10] and Table D-1 of Semadeeni-Davies

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9 Cox, Timothy Jason (2019) Evidence in Chief submitted prior to Block 1 hearings, submitted on behalf of Beef + Lamb New Zealand.

10 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

et al., 2015[11]). The RDST produced a mean annual load of TN that was very similar to the mean annual load from the HRWO model and which fitted within the range of mean annual loads estimated from boot-strapping analysis on the monitored TN and flow data. The RDST produced conservative estimates for the TP and E. coli mean annual loads over the 2010-14 period at Ohakuri Tailrace, when compared with the monitoring data. The HRWO model also over-predicted the E. coli mean annual load at Ohakuri. Although the RDST over-estimated E. coli loads at several sites, from Figure 10 the 95th percentile E. coli concentration from the RDST was a good predictor of the monitored concentration. Because the RDST produced load and concentration estimates at the downstream extent of the catchment, Ohakuri Tailrace, that were either well matched to the monitoring data or conservative (high) estimates, it would be possible to use the outputs from the RDST at Ohakuri Tailrace to predict changes in outcomes for constituent loads and concentrations at sites on the Waikato River downstream of Lake Ohakuri.

*Table 2 Mean annual loads of TN, TP and E. coli for the Waikato River at Ohakuri Tailrace (downstream extent of the RDST) for 2010-14 from monitoring data, HRWO model and the RDST calibration model run*

| | **2010-2014 monitored data and range from boot-strapping** | **HRWO model** | **RDST calibration model** |
|---|---|---|---|
| **Mean annual TN load (t/y)** | 1519.8 (1376.2-1719.7) | 1453.3 | 1457.1 |
| **Mean annual TP load (t/y)** | 135.4 (123.5-144.1) | 138.7 | 169.4 |
| **Mean annual E. coli load (10^15 organisms/y)** | 0.30 (0.23-0.51) | 0.77 | 2.95 |

55 I would propose two potential options for integrating predictions from the RDST with modelling of the catchment downstream of Ohakuri Tailrace, in order to infer the influence of land use and mitigations undertaken in the upper catchment (i.e. upstream of Lake Ohakuri) on in-stream water quality in the Waikato River downstream of Lake Oharkuri:

55.1 A dynamic model could be developed for the remainder of the Waikato River catchment, using the same or similar model framework to that used for the RDST.

55.2 Further scenarios could be run with the HRWO CLUES model, but with the ten upper sub-catchments excluded from the

[11] 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

model and replaced with contaminant inputs produced by outputs from the RDST.

56 Whilst the second proposed approach would fail to overcome some of the shortcomings of the HRWO model that I expressed in my Block 1 EIC, it would make progress toward addressing the deficiencies associated with the assumed TN “load to come” from the upper catchment that was contained within the HRWO baseline model. The approach is likely to require considerably fewer resources for additional model simulations than the first, since the HRWO model already exists. Indeed, Dr. Cox demonstrated in his Block 1 EIC that he had created a model that replicated many features of the HRWO model using publicly available data.

***Capacity of the RDST to address additional water quality constituents***

57 The RDST has currently been calibrated to provide estimates of concentrations and loads for the four contaminants that are addressed explicitly in PC1, TN, TP, TSS and E. coli. The computational framework of the RDST is sufficiently flexible that additional constituents could be included at some later time.

58 Species of nutrients, including Dissolved Reactive Phosphorus (**DRP**), Particulate Phosphorus, Ammonium, Nitrate and Nitrite Nitrogen (**NNN**), Dissolved Inorganic Nitrogen (**DIN**), Total Kjeldahl Nitrogen (**TKN**) and Dissolved Organic Nitrogen (**DON**) could be included in the model at some later time, if desired. Additional work would be required to collect and compile monitoring data for these constituents and to calibrate the RDST to represent these additional constituents. Additional work may also be required to represent processes for transformations between species of nutrients through the catchment and stream network. In my experience, I have seen nutrient species successfully modelled using catchment models that are similar in form to the RDST in other catchments in the past.

59 Dissolved Oxygen (**DO**) and water temperature are two other attributes that could be represented in the RDST. The RDST currently operates at a daily time step and DO and temperature are two attributes that normally exhibit diurnal cycles. As the RDST is currently a daily time step model, inclusion of DO or temperature in the model would require either the RDST to run on a sub-daily time. Additional work would also be required to collect and compile monitoring data for these constituents and to calibrate the RDST to represent these additional constituents.

**CONCLUSIONS**

60 In my EIC for the Block 1 hearings, I articulated aspects of the HRWO modelling that were, in my view, not adequate in accurately capturing the hydrological and water quality response of the catchment. In my view, those deficiencies in modelling contaminants undermined the reliability of conclusions made using the modelling to support the argument that PC1 fulfils the requirements of the RMA.

61 WPL developed a catchment scale model of the upper portion of the Waikato River catchment, referred to as the RDST. The RDST covers the spatial extent of the upper Waikato River catchment, between Taupo Gates and Lake Ohakuri. The RDST was developed and calibrated in a manner that addressed the shortcomings that I had identified in the HRWO modelling.

62 In my EIC for Block 1, I also pointed out the shortcomings of applying the steady-state HRWO model to predict concentrations and loads of TN, TP and E. coli. The RDST is a dynamic model, which explicitly models rainfall, runoff, surface and groundwater processes and contaminant loads and concentrations on a daily time step. As discussed above, supported by the documentation presented in Mawer et al. (2019), the RDST reproduced the temporal dynamics of flow, TN, TP, TSS and E. coli concentrations that were observed in monitoring data across several decades of available data collection.

63 The RDST was capturing the temporal variations well at the majority of the monitoring sites, including higher TN concentrations during surface runoff events, seasonal variations in TN concentration associated with seasonal variations in groundwater discharge and, for several sites, gradual increase in TN associated with land use change. For the ten monitoring sites in the upper Waikato catchment (RDST model domain), the RDST produced a similar level of accuracy in predicting mean annual TN loads for the 2010-2014 period to the HRWO model.

64 The RDST also predicted the variability in TP and TSS concentrations seen in monitoring data at the majority of monitoring sites, including higher concentrations during surface runoff events. For the ten monitoring sites in the upper Waikato catchment (RDST model domain), the RDST produced a similar level of accuracy in predicting mean annual TP loads for the 2010-2014 period to the HRWO model. There was an insufficient number of sites with adequate monitoring data to make a comparison between the HRWO and RDST models for TSS in the upper catchment.

65 Neither the RDST nor the HRWO models produced particularly accurate calibrations to E. coli loads over this period. However, the RDST produced reasonable estimates of the 95$^{th}$ percentile E. coli concentrations across the nine monitoring sites in the upper catchment.

66 The RDST is a dynamic model, which was calibrated to all of the available streamflow gauging and water quality monitoring data. At several sites, the monitoring data extends from 1993 to 2018. The parameter values in the RDST were therefore calibrated to water quality monitoring data collected over the full data collection period and were not limited to the 2010-2014 period only. As the RDST models the temporal dynamics of the system, it may be run to reliably predict the influences of changes in land use, land management and mitigation actions, without the concern that parameter values adopted in the RDST were particularly tuned to the climatic conditions that occurred over the 2010-2014 baseline period. The RDST possessed an advantage over the HRWO model in this respect, as the parameters of the HRWO model may be biased by the selection of the baseline period adopted for calibration.

67 An uncertainty analysis is currently being undertaken for the RDST to address any parallel concerns to the HRWO models about lack of understanding of uncertainty or sensitivity of the RDST model predictions to input data and parameterisation.

68 The RDST produced a mean annual load of TN that was very similar to the mean annual load from the HRWO model and which fitted within the range of mean annual loads estimated from boot-strapping analysis on the monitored TN and flow data. The RDST produced conservative estimates for the TP and E. coli mean annual loads over the 2010-14 period at Ohakuri Tailrace, when compared with the monitoring data. Because the RDST produced load and concentration estimates at the downstream extent of the catchment, Ohakuri Tailrace, that were either well matched to the monitoring data or conservative (high) estimates, it would be possible to use the outputs from the RDST at Ohakuri Tailrace to predict changes in outcomes for constituent loads and concentrations at sites on the Waikato River downstream of Lake Ohakuri.

69 The RDST has demonstrated that it is possible to model contaminant concentrations and loads for a sub-catchment arrangement with a finer spatial resolution than would be determined from the monitoring network. Previous evidence demonstrates that there are sound hydrological and ecological reasons to separate sub-catchment 66 of PC1 into sub-catchments 66A and 66B, and the RDST provides the ability to set water quality objectives at the intersection between the two new sub-catchments. Water quality monitoring at this site is recommended to confirm the calibration of the RDST at this site (and I understand that this is available from the RQ1 monitoring site, referenced in the SOURCE model reporting prepared by Mr Williamson).

**Phillip William Jordan**

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3 May 2019