BEFORE COMMISSIONERS APPOINTED
BY THE WAIKATO REGIONAL COUNCIL

IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of the First Schedule to the Act
AND	
IN THE MATTER	of Waikato Regional Plan Change 1- Waikato and Waipā River Catchments and Variation 1 to Plan Change 1
AND	
IN THE MATTER	of submissions under clause 6 First Schedule
BY	**BEEF + LAMB NEW ZEALAND LIMITED** **Submitter**

BRIEF OF EVIDENCE OF TIMOTHY JASON COX

3 May 2019

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BACKGROUND

1. My full name is Timothy Jason Cox.

2. I am a water resources engineer and scientist, specializing in water quality and hydrologic modelling. I have nearly 20 years of experience in water resources science and consulting, with a focus on numerical modelling of freshwater systems.

3. I hold a Bachelor of Sciences degree in Civil and Environmental Engineering from Duke University (USA), a Masters degree in Water Resources Engineering from the University of Colorado (USA), a Master of Philosophy degree in Science and Technology from the University of Waikato, and a Doctor of Philosophy degree in Engineering Science from the University of Auckland. My doctorate research focused on nitrogen fate and transport in small streams.

4. I gave evidence for Beef + Lamb New Zealand Ltd (B+LNZ) as part of its case on the hearing stream 1 (HS1) topics. In my HS1 evidence, dated 15 February 2019, I set out my qualifications, current employment and employment history and professional affiliations. I confirm those details remain current.

5. In preparing this evidence I have reviewed:

   (a) The reports and statements of evidence of other experts giving evidence relevant to my area of expertise, including:

      (i) Ms Alison Dewes;

      (ii) Dr Jane Chrystal;

      (iii) Mr Simon Stokes;

      (iv) Dr Alec Mackay;

      (v) Mr Richmond Beetham;

   (b) The Council Officers' section 42A report;

(c) Plan Change 1 and Variation 1; and

(d) The section 32 report.

6. I reconfirm that I have read the Code of Conduct for Expert Witnesses in the Environment Court's 2014 Practice Note and agree to comply with it. I confirm that the opinions I have expressed represent my true and complete professional opinions. The matters addressed by my evidence are within my field of professional expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

SCOPE OF EVIDENCE

7. I have been requested by Beef + Lamb New Zealand to provide expert evidence on catchment modelling of landuse and water quality as it relates to the modelling underpinning the proposed Waikato Regional Plan Change 1 (WRPC1). My focus is on nutrients.

8. I previously submitted evidence for Hearing Stream 1 that presents my own modelling work which builds on the catchment modelling performed by the NIWA team. For that evidence, I used my model to better characterise current conditions in the river basin, investigate model uncertainty and sensitivities, and provide general insight on the proposed water quality outcomes and basin mitigation strategies for achieving those outcomes. For details on the constructed model, parameterisation, and modelling software, I refer the reader to this earlier evidence.

9. In this evidence, developed for Hearing Stream 2, I use the constructed model to investigate alternative nitrogen allocation policies. The simulation presented below are intended to supplement the predictive simulations already performed by the Healthy Rivers technical team and to gain greater insight into the feasibility and effectiveness of various alternative mitigation strategies to better inform final policy setting. Note that, for all simulations presented here, the original baseline model parameter set (which replicate the NIWA model parameters) was used as the starting point for each scenario construction. Any changes to the baseline parameters are described below, for each scenario.

NITROGEN MODEL RECALIBRATION

10. As described in my Hearing Stream 1 evidence, I calibrated the model used to support that evidence to precisely match the parameterisation of the NIWA catchment model developed for the Collaborative Stakeholder Group (CSG). The NIWA model was calibrated using river water quality data measured during the 2010 through 2014 monitoring period. For the work that I present in this second stream of evidence, I have re-calibrated my model using data that is more reflective of current conditions and that I also have greater confidence in.

11. I re-calibrated the nitrogen attenuation coefficients in my model using the most recent water quality data available, for the period 2017 through 2018. I also updated landuse in the model to reflect current conditions, using the 2018 Agribase landuse layer. Lastly, I updated assumed dairy and dry stock export coefficients based on analyses described in Paragraphs 121 – 128 of my Hearing Stream 1 evidence. Based on those analyses, which used a more up-to-date version of Overseer, I assumed a 50% increase in export coefficients, from baseline, for both farm types for this re-calibration. These appear to be a more accurate representation of current export coefficients for pastoral farm lands, compared to those used in the original modeling.

12. Prior to calibrating the updated model, I reviewed the measured nitrogen data for a subset of the mainstem calibration sites. My intent was to assess whether the most recent data (2017 – 18) was statistically different than the original calibration data set (2010 – 2014). For this exercise, I reviewed the measured concentrations since 2013. This data was provided by Waikato Regional Council. Results of this analysis (Figure 1) show that measured nitrogen data exhibit statistically significant increasing trends at all three of the selected mainstem calibration sites for the given period. Local variability in these plots appears to be largely seasonal.

13. I achieved a new nitrogen model calibration by adjusting attenuation coefficients in the updated model to best fit modeled mainstem nitrogen concentrations with recent (2017 – 18) measured concentrations. I used an optimisation fitting routine, provided in my modeling software ("auto-

calibration"), to achieve this. Downstream measured median nitrogen concentrations were matched exactly by the calibrated model for all mainstem calibration locations.

14. Results show an overall increase in nitrogen attenuation in the catchment in the new model, compared to the original NIWA model. The overall areal-weighted average nitrogen attenuation coefficient for the catchment increased from 28% (original NIWA model) to 42% (updated calibration model). This is not unexpected, as I believe that both dairy farm land areas, and pastoral farm export coefficients, were underestimated in the original NIWA model. This underestimation of loading would have led to an underestimation of catchment attenuation in their calibration process.

15. Source tracking in the model allows for relative summaries of total mass contributions from various land use categories at specified locations. These summaries include the impacts of attenuation. Such summaries, for the newly calibrated model, are shown in Figure 2. Results show that the relative contributions of total nitrogen loads at the various locations of interest have changed relative to the original (NIWA) model construct (Figure 2 of my Hearing Stream 1 evidence). More specifically, the relative contribution of dairy to the total nitrogen loads is generally higher in the updated model. For example at Ohakuri, the relative contribution from dairy (including dairy support) has increased from 31% to 61%. At the bottom of the catchment (Port Waikato), the total dairy contribution has increased from 55% to 68%. Conversely, the modeled relative contribution of dry stock to N loads has generally decreased at all sites in the updated model. At those same locations, respectively, dry stock contributions have decreased from 34% to 10% and from 35% to 19%. As noted above, I believe that the updated model is a more accurate reflection of current conditions than the original model.

Figure 1a: Measured Nitrogen Concentrations, Waikato River at Ohakuri, 2013 – 2018

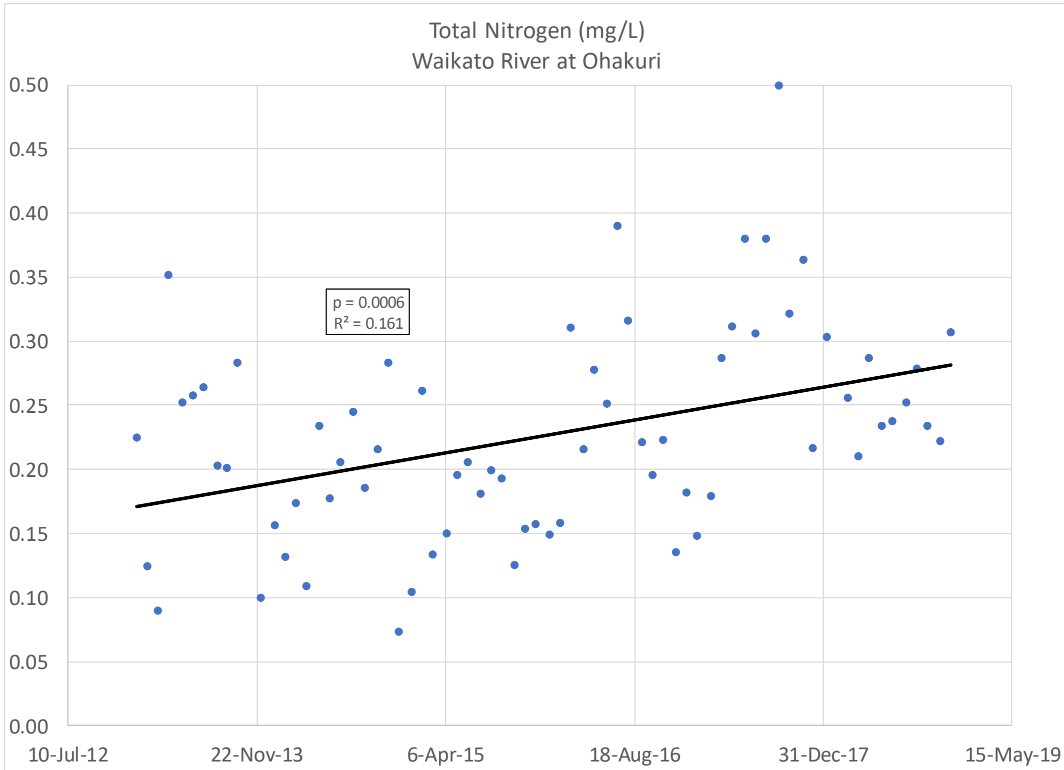


Figure 1b: Measured Nitrogen Concentrations, Waikato River at Narrows Bridge, 2013 – 2018

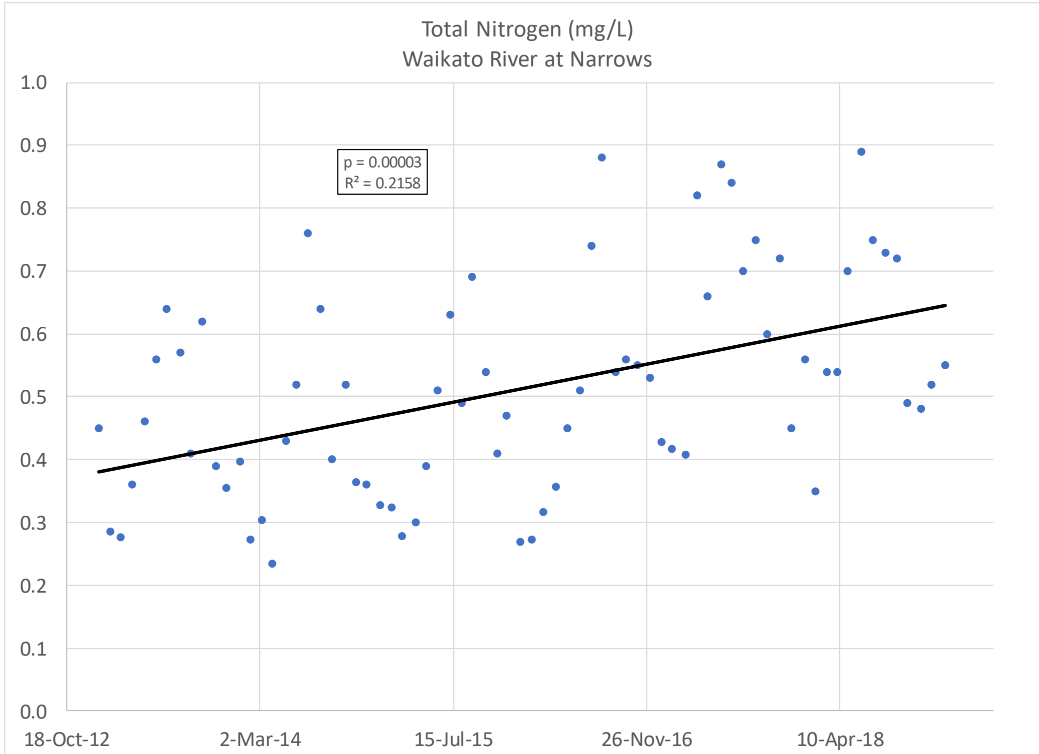


Figure 1c: Measured Nitrogen Concentrations, Waikato River at Tuakau, 2013 - 2018

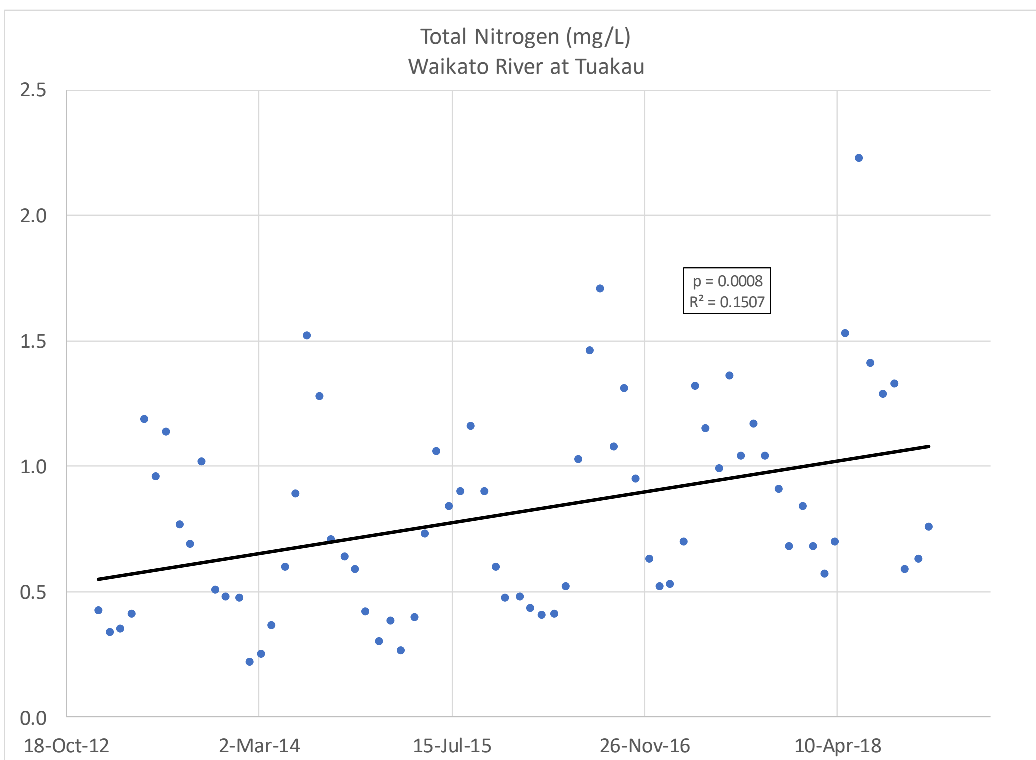
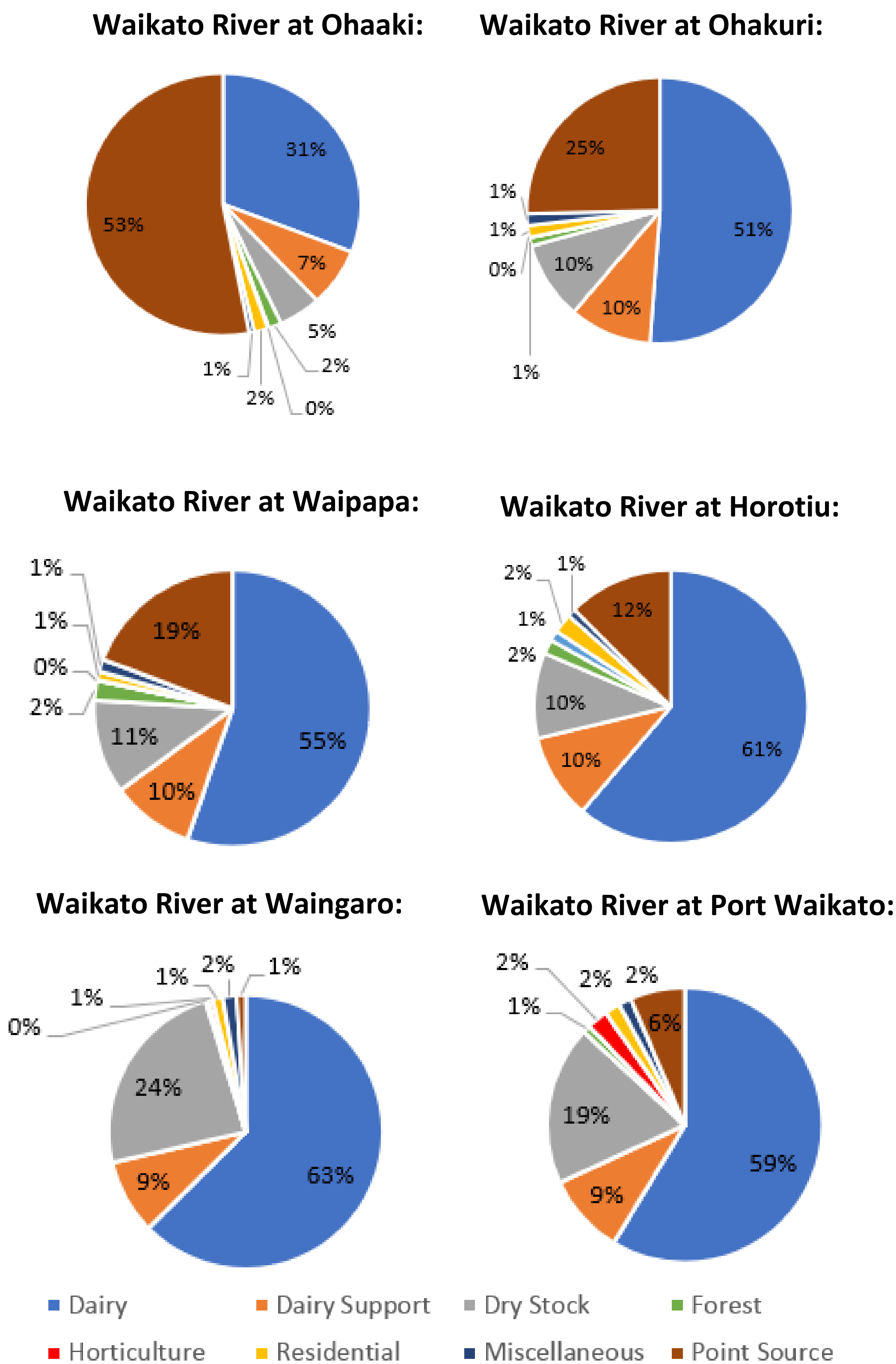


Figure 2: Re-Calibrated Model Mass Balance Summaries, TN: Relative Proportions



DRIVERS OF WATER QUALITY CHANGE IN THE CATCHMENT

16. Figure 1 clearly demonstrates that nitrogen levels in the Waikato River mainstem have increased over the past six years. To investigate potential drivers of this change, I applied the updated calibration model using two different landuse snapshots (2006 and 2018) to quantify changes in total nitrogen export, by sector.

17. The only difference between these two model simulations was the landuse layer used. Export coefficients were maintained at those values used in the updated calibration model.

18. Results (Table 1) show that dairy exports in the catchment have likely increased significantly over the past 10 – 12 years. Modelled dairy exports are approximately 30% higher for the 2018 snapshot, compared to the 2006 simulation. The model indicates that total nitrogen loads from dry stock and forest have decreased over that same time period.

19. These results highlight the likely primary driver of the rising river nitrogen concentrations shown in Figure 1: an increase in dairy farming in the catchment.

Table 1: Modelled Total Catchment Nitrogen Export (tpy), by Sector

	2006	**2018**
Dairy	16,022	20,703
Dry stock	6,103	5,530
Forest	608	387
Other	1,336	1,503

PREDICTIVE MODELLING 1: EQUAL ALLOCATION

20. I used the updated calibration model to perform a series of predictive simulations investigating alternative nitrogen allocation strategies.

21. In the first set of simulations, I investigated the ability of the catchment to achieve downstream nitrogen targets under an assumption of "equal allocation" of diffuse-source nitrogen discharges.

22. This set of simulations corresponds with the equal allocation scenario that I presented in my evidence for Hearing Stream 1. The primary difference here is that I am using the updated calibration model.

23. I also include here a new set of proposed instream nitrogen concentration longer term Targets. These targets were derived by a weight of evidence approach, for establishing instream nitrogen and phosphorus outcomes to provide for freshwater ecosystem health[1], as discussed by Dr Mueller in her HS1 evidence[2], and are summarised in Table 2. This approach has been supported by the Science Technical Advisory Group as part of the national working group for "Essential Freshwater", and will be considered further through expert conferencing. I have no opinion, one way or the other, with respect to their appropriateness for achieving the long-term strategy and vision in this catchment, as this matter is outside of my area of expertise. I merely present them as informative alternative longer-term outcomes, by which scenarios can be tested. Such scenarios include investigating the implications for land use and communities under various instream nitrogen constraints.

24. For this set of scenarios, I quantified the equal nitrogen export allocation required to achieve both the existing long-term targets proposed for Plan

[1] Death, R. G., Canning, A., Magierowski, R. and Tonkin, J., 2018. Why aren't we managing water quality to protect ecological health?. In: Farm environmental planning – Science, policy and practice. (Eds L. D. Currie and C. L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 31. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 13 pages.

[2] Evidence in Chief Dr Mueller on behalf of B+LNZ (2019), para 59, page 27

Change 1 (WRC, 2016) and this new set of proposed instream nitrogen outcomes for ecological health.

Table 2: Alternative Instream Nitrogen Targets

Narrative State	Max TN Concentration (mg/L)[3]	Waikato FMU
Minimal N enrichment	0.25	Upper Waikato
Moderate N enrichment	0.51	Middle Waikato
Substantial N enrichment	0.81	Lower Waikato

[3] = annual median based on monthly monitoring

25. For this exercise, I allocated all upstream properties the same nitrogen export allowance (kg ha^{-1} yr^{-1}), regardless of current land use (including forestry). In the first instance, I set downstream nitrogen attribute targets (mg l^{-1}) in the model, for each specified monitoring location, equal to the two sets of targets described above. All point sources in the model were held steady, at current discharge levels, for these simulations. I used the model to determine the uniform export coefficient value, for all upstream properties, required to achieve downstream attribute targets. As a follow-up, I performed the same type of simulations for water quality targets roughly equal to current median concentrations (maintaining current conditions).

26. Plan Change 1 presents long-term median nitrogen concentration targets for multiple locations along the Waikato River mainstem. These targets were developed as part of the Healthy Rivers study to ensure that the entire length of the river is “safe to swim in and take food from”. In addition to the long-term targets, short-term (10 year) interim median concentration targets are also presented. These values represent 10% of the total reduction needed to achieve long-term targets. Using these short-term targets, I deduced current median concentrations for each location, which were then truth-checked against published data, using the following equation:

$$X_1 - X_2 = 0.1 * (X_1 - X_3),$$

where X_1 = current median concentration, X_2 = short-term median concentration target, and X_3 = long-term median concentration target. In this equation, both X_2 and X_3 are known (published), and X_1 is solved for using simple algebraic manipulations. Additionally, to translate load predictions into concentrations in the model, river flow rates must be assumed. Using the calculated current median concentrations, combined with modelled current total instream nitrogen loads at each location, I calculated representative flow rates ($m^3\ s^{-1}$) with the following equation:

$$Q_1 = \frac{L_1}{X_1}$$

where Q_1 = implied current flow rate and L_1 = modelled current total annual instream load at the location of interest. This calculated flow rate simply serves as a consistent reference value to be used for predictive modeling of river concentrations, and (in theory) roughly corresponds to the median flow rate at each location. The flow rates at each targeted location were assumed steady for this exercise (i.e. future reference flow rate = current reference flow rate).

27. With flow rates set as steady values in the model, I followed an iterative approach to determine the equal allocation export requirements. The process was performed for each of the downstream target locations. I set upstream export coefficients to a uniform initial value, across all sub-catchments and land use types. I then adjusted the export coefficients, uniformly, within a series of model runs until the downstream target was achieved.

28. In addition to simulating the achievement of prescribed future targets, I also used the model to quantify an equal allocation distribution associated with maintaining current conditions. The process followed the same procedure as described above, but current median nitrogen concentrations were substituted for the long-term targets. The results demonstrate how nutrient loads might be equally allocated across the catchment to maintain current water quality conditions. These results also provide a useful baseline reference for assessing

the implications of the long-term simulation results, with respect to the required changes in catchment exports.

29. Results of this exercise are summarised in **Tables 3 and 4**. Results show that equal allocation export requirements, to achieve long-term targets, vary widely across downstream monitoring locations. This variability in outcome is due to the combined variability in the following input parameters: prescribed target concentrations (higher at downstream locations), drainage areas, upstream point sources, assumed flow rates, and sub-catchment attenuation coefficients. For example, the Whakamaru and Waipapa sites are shown to be the most stringent, with respect to required changes in upstream exports. This appears to be due to the lower target concentrations (0.16 and 0.25 mg/L) combined with significant upstream drainage area and relatively high (per unit drainage area) upstream point source loading.

30. Comparison to the current condition equal allocation scenario indicates that diffuse exports, on average, require net reductions of between 57 to 90%, overall, to achieve long-term PC1 targets. This assumes point source discharges remain unchanged in the future. Comparison to land use-specific baseline current exports, indicate that target long-term export coefficients, under an equal allocation scenario, are generally lower than assumed current dry stock values and significantly lower than assumed dairy export values. For one location (Waipapa), the target equal allocation export coefficient is only slightly higher than the assumed value for forested lands, implying the need for nearly full upstream reforestation. One of the constraining factors for this site is the presence of relatively high upstream point source loads, including the load from Kinleith Pulp Mill, just upstream of the site.

31. For the alternative freshwater ecosystem longer term targets, diffuse load reduction requirements are significantly less than those associated with the long-term PC1 targets, ranging from 13 to 55%. Diffuse source allocations range from 14 to 25 kg-N ha-1 yr-1, depending on the water quality station of interest. According to these results, to achieve the stated targets across all water quality stations, including the constraining point at Waipapa, an equal allocation of no more than 14 kg-N ha^{-1} yr^{-1} is required.

Table 3: Equal Allocation Modelling Results: Existing PC1 Long-Term Targets

Waikato River Station	Upstream Drainage Area (ha)	Assumed Flow (cms)	Current Median Conc. (mg/L)	Target Median Conc. (mg/L)	Current Condition Equal Allocation Export Coeff. (kg-N/ha/yr)	Target Equal Allocation Export Coeff. (kg-N/ha/yr)	Required Diffuse Load Reduction[1]
Ohakuri	160,477	209	0.28	0.16	28	11.5	69%
Whakamaru	241,422	214	0.37	0.16	27	8.5	80%
Waipapa	333,000	238	0.41	0.16	26	6.3	90%
Narrows	465,871	315	0.63	0.35	31	15.5	57%
Horotiu	497,368	330	0.68	0.35	30	13.5	63%
Huntly	876,303	540	0.88	0.35	28	9.5	77%
Mercer	1,042,981	557	0.92	0.35	26.5	9	78%
Tuakau	1,067,000	629	0.83	0.35	29.5	10	76%

[1] = relative to load in excess of natural background load

Table 4: Equal Allocation Modelling Results: Alternative Freshwater Ecosystem targets

Waikato River Station	Upstream Drainage Area (ha)	Assumed Flow (cms)	Current Median Conc. (mg/L)	Target Median Conc. (mg/L)	Current Condition Equal Allocation Export Coeff. (kg-N/ha/yr)	Target Equal Allocation Export Coeff. (kg-N/ha/yr)	Required Diffuse Load Reduction[1]
Ohakuri	160,477	209	0.28	0.25	28	24	17%
Whakamaru	241,422	214	0.37	0.25	27	16	48%
Waipapa	333,000	238	0.41	0.25	26	14	55%
Narrows	465,871	315	0.63	0.51	31	24.5	24%
Horotiu	497,368	330	0.68	0.51	30	21.5	33%
Huntly	876,303	540	0.88	0.8	28	25	13%
Mercer	1,042,981	557	0.92	0.8	26.5	22.5	18%
Tuakau	1,067,000	629	0.83	0.8	29.5	25	18%

[1] = relative to load in excess of natural background load

PREDICTIVE MODELLING 2: FLEXIBLE CAP

32. I performed a second set of simulations to investigate the implications of a flexible cap scenario, whereby lower leaching properties (dry stock) are allowed.

33. For these simulations, I modified exports from existing dry stock model objects based on farm land class. Assumed export coefficients, by land class, are summarised in Table 5. Land class areas, by sub-catchment, were provided by Waikato Regional Council. I calculated effective dry stock export coefficients (Table 6), for each sub-catchment model object, as a function of land class area and the associated export coefficients. In all cases, the modified effective export coefficients were lower than baseline values assumed in the updated calibration model. In a small number of cases, the modified effective export coefficients were slightly lower than baseline. The overall basin-wide average dry stock export coefficient was decreased from 16.1 to 11.0 kg ha-1 yr-1.

34. As part of these simulations, and simultaneous to the prescriptive dry stock export modifications, I set nitrogen exports from higher leaching properties (dairy and dairy support) as variables within a model mitigation optimisation simulation. In this simulation mode, variable export coefficients are systematically, and optimally, reduced in the model until prescribed water quality objectives are achieved. I performed two optimisation simulations: one to achieve Plan Change 1 long-term (80-year) nitrogen concentration targets and a second to the proposed alternative freshwater ecosystem targets. The model algorithm optimises variable export coefficients to achieve water quality targets at all water quality stations. Optimality is determined based on relative spatial location of each sub-catchment and associated attenuation coefficients. For these scenarios, only dairy and dairy support, exports were varied (optimisation variables); all other land use exports, and point sources, were maintained at prescribed baseline levels.

35. Simulation results (Table 7) highlight the need for significant reductions in dairy nitrogen exports, along with the reduced dry stock exports noted above, to achieve stated water quality targets. To achieve the current PC1 long-term

targets in the upper catchment, under such an allocation scheme, nearly 100% afforestation of dairy lands would be required. On the order of 80 – 90% afforestation would be required for the middle and lower catchment. For the alternative freshwater ecosystem health targets, the required export load reductions are more moderate, particularly in the middle and lower catchments (on the order of 25% afforestation).

Table 5: Farm Class Export Coefficients, Flexi-Cap Simulation Scenario

Farm Class	**Export Coefficient Rule**
I	*30% of farms move to 15 kg-N ha-1 yr-1*
II	*100% of farms move to 10 kg-N ha-1 yr-1*
IIIa	*No change*
IIIb	*25% of farms move to 15 kg-N ha-1 yr-1, 25% of farms move to 20 kg-N ha-1 yr-1*
IV	*20% of farms move to 15 kg-N ha-1 yr-1, 20% of farms move to 20 kg-N ha-1 yr-1*

Table 6: Flexi-Cap Scenario Modified Dry Stock Export Coefficients

Sub-Catchment	**Baseline Dry Stock Export Coefficient (kg-N ha-1 yr-1)**	**Modified Dry Stock Export Coefficient (kg-N ha-1 yr-1)**
Awaroa (Waiuku) (52)	15.5	10.7
Awaroa at Harris/Te Ohaki Br (36)	15.5	10.7
Awaroa at Sansons Br (37)	15.5	10.7
Firewood (121)	15.5	11.6
Kaniwhaniwha (118)	15.3	11.7
Karapiro (22)	17.1	11.7

Sub-Catchment	Baseline Dry Stock Export Coefficient (kg-N ha-1 yr-1)	Modified Dry Stock Export Coefficient (kg-N ha-1 yr-1)
Kawaunui (7)	17.6	10.7
Kirikiriroa (31)	17.2	11.7
Komakorau (33)	15.6	11.7
Little Waipa (20)	17.7	11.7
Mangaharakeke (14)	17.6	11.7
Mangakara (5)	17.6	12.6
Mangakino (16)	17.6	11.7
Mangakotukutuku (27)	17.3	11.2
Mangamingi (17)	17.6	10.7
Mangaohoi (115)	16.5	11.6
Mangaokewa (102)	15.3	11.6
Mangaone (28)	17.0	10.7
Mangaonua (26)	17.1	10.7
Mangapiko (114)	15.4	10.7
Mangapu (104)	15.3	10.7
Mangarama (105)	15.3	10.7
Mangarapa (103)	15.3	10.7
Mangatangi (46)	15.5	10.7
Mangatawhiri (49)	15.6	11.6
Mangatutu (113)	15.3	10.7
Mangauika (117)	15.3	10.7
Mangawara (34)	15.5	10.8

Sub-Catchment	Baseline Dry Stock Export Coefficient (kg-N ha-1 yr-1)	Modified Dry Stock Export Coefficient (kg-N ha-1 yr-1)
Mangawhero (24)	17.1	10.7
Matahuru (43)	15.5	11.7
Moakurarua (110)	15.3	11.7
Ohaeroa (48)	15.6	11.7
Ohote (120)	15.6	10.7
Opuatia (45)	15.5	11.7
Otamakokore (9)	17.6	11.7
Pokaiwhenua (19)	17.6	10.7
Pueto (1)	17.6	11.6
Punui at Bartons Corner Rd Br (111)	15.3	10.7
Punui at Wharepapa (112)	15.3	11.7
Tahunaatara (13)	17.6	10.7
Torepatutahi (4)	17.6	11.6
Waerenga (42)	15.6	11.7
Waikare (44)	15.5	11.7
Waikato at BridgeSt Br (Ham Traffic Br) (25)	17.2	10.7
Waikato at Horotiu Br (29)	17.2	11.7
Waikato at Huntly-Tainui Br (32)	15.5	11.7
Waikato at Karapiro (21)	17.6	11.7
Waikato at Mercer Br (38)	15.5	11.7
Waikato at Narrows (23)	17.1	10.7
Waikato at Ohaaki (2)	17.6	10.7

Sub-Catchment	Baseline Dry Stock Export Coefficient (kg-N ha-1 yr-1)	Modified Dry Stock Export Coefficient (kg-N ha-1 yr-1)
Waikato at Ohakuri (3)	17.6	10.7
Waikato at Port Waikato (50)	15.5	11.7
Waikato at Rangiriri (35)	15.5	12.6
Waikato at Tuakau Br (47)	15.5	10.7
Waikato at Waipapa (15)	17.6	10.7
Waikato at Whakamaru (11)	17.6	10.7
Waiotapu at Campbell (8)	17.6	11.7
Waiotapu at Homestead (6)	17.7	10.7
Waipa at Mangaokewa Rd (100)	15.3	10.7
Waipa at Otewa (101)	15.3	10.7
Waipa at Otorohanga (106)	15.3	11.7
Waipa at Pirongia-Ngutunui Rd Br (107)	15.3	10.7
Waipa at SH23 Br Whatawhata (116)	15.3	10.7
Waipa at Waingaro Rd Br (119)	15.5	11.6
Waipapa (12)	17.6	10.7
Waitawhiriwhiri (30)	17.3	10.7
Waitomo at SH31 Otorohanga (109)	15.3	10.7
Waitomo at Tumutumu Rd (108)	15.3	10.7
Whakapipi (51)	15.6	10.7
Whakauru (18)	17.7	10.7
Whangamarino at Island Block Rd (40)	15.5	10.7
Whangamarino at Jefferies Rd Br (41)	15.5	10.7

Sub-Catchment	Baseline Dry Stock Export Coefficient (kg-N ha-1 yr-1)	Modified Dry Stock Export Coefficient (kg-N ha-1 yr-1)
Whangape (39)	15.5	10.7
Whirinaki (10)	17.6	10.7

Table 7: Flexi-Cap Scenario Modeling Results

Station	**Mainstem Loc. (km)**	**Baseline Conc. (mg-N/L)**	**Long-term PC1 Target Conc. (mg-N/L)**	**Alternative Target Conc. (mg-N/L)**	**Baseline Dairy Upstream Avg. Export Coeff. (kg-N/ha/yr)**	**Long-term Dairy Upstream Avg. Export Coeff. (kg-N/ha/yr)**	**Alternative Diary Upstream Avg. Export Coeff. (kg-N/ha/yr)**
Ohakuri	78	0.28	0.16	0.25	50.0	4.0	8.4
Whakamaru	107	0.37	0.16	0.25	53.0	4.0	7.2
Waipapa	130	0.41	0.16	0.25	54.8	5.3	18.7
Narrows	208	0.63	0.35	0.51	55.2	8.7	32.4
Horotiu	232	0.68	0.35	0.51	54.5	8.4	32.0
Huntly	255	0.88	0.35	0.8	50.8	6.5	38.1
Mercer	294	0.92	0.35	0.8	49.6	8.1	37.7
Tuakau	305	0.83	0.35	0.8	49.5	8.3	37.7

PREDICTIVE MODELLING 3: LAND USE CAPABILITY CLASS ALLOCATION

36. I simulated a scenario where nitrogen export allowances were allocated based only on land use capability class (LUC) designations within each sub-catchment. In other words, allocations were made based on a given sub-catchment's innate natural productive capacity.

37. Areal LUC data for each sub-catchment were provided by Waikato Regional Council. This data is summarised in Figure 3 and Table 8. I assigned each LUC class, for each of the four basin freshwater management units (FMUs), a starting nitrogen export allowance, based on Top Farmer attainable potential livestock carrying capacity numbers as set out in the Evidence in Chief of Dr MacKay. I calculated sub-catchment starting effective nitrogen export coefficients based on LUC areal coverages and the assigned class allowances. In an iterative process, I then uniformly adjusted this initial sub-catchment export coefficients until the prescribed nitrogen concentration targets were achieved at all water quality stations in the model. The same percent adjustment factor was applied to all sub-catchments in the model, thus retaining the original allowance ratios based on LUC designations. In other words, the relative distribution of nitrogen allocations was based directly on assigned livestock carrying capacities for each LUC class.

38. For this exercise, I assumed nitrogen exports from forested land (i.e. background) to be 4 kg-N/ha/year. This was the minimum allocation allowed in the model.

39. Point source loads were retained at baseline levels for this exercise. In other words, point sources were assumed to remain unchanged for these future scenarios.

40. Nitrogen concentration targets used for this exercise were set, firstly, using the draft PC1 long-term targets and, secondly, based on the proposed alternative freshwater ecosystem health targets.

41. Results indicate that a LUC-based allocation of nitrogen could achieve the stated targets with the allowances shown in Tables 9 and 10. The basin-wide,

area-weighted average export allowance required to achieve PC1 long-term targets is 7 kg-N/ha/yr; while the weighted average allowance required to achieve the alternative freshwater ecosystem health targets is 16 kg-N/ha/yr. The constraining water quality station in this exercise, for both sets of targets, was the Waikato at Waipapa site (0.16 and 0.25 mg/L targets, respectively). The targets were achieved at this site exactly with the allocations shown. At all other sites, resulting modeled concentrations were lower than the targets.

Table 8: Land Use Area (ha) by Land Use Capability for Waikato PC1 Catchment

LUC Class	**hectares**	**%**
1	20,920	1.9%
2	153,523	14.0%
3	152,801	13.9%
4	196,965	17.9%
5	3,490	0.3%
6	415,854	37.9%
7	116,501	10.6%
8	15,943	1.5%
lake	8,707	0.8%
nocor	1,989	0.2%
quar	706	0.1%
rive	1,964	0.2%
town	8,646	0.8%
Total PC1 Area	1,098,007	100.0%

Table 9: LUC-Based Allocation Modelling Results: Nitrogen Allocations to Achieve PC1 Long-Term Targets

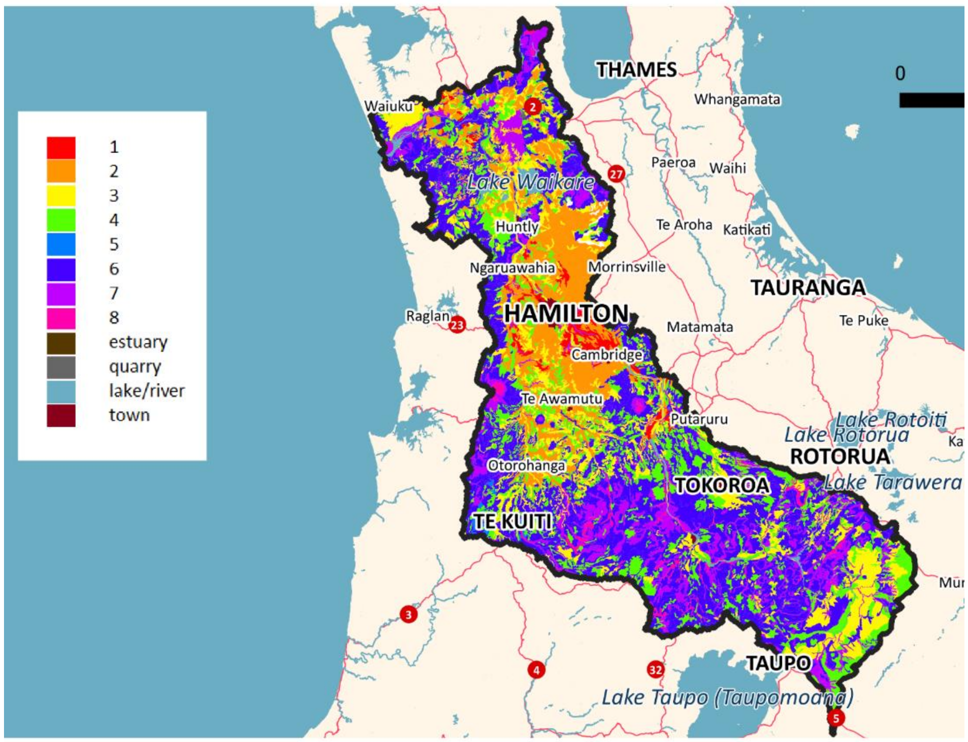
LUC Class	Upper Waikato (kg-N/ha/yr)	Middle Waikato (kg-N/ha/yr)	Lower Waikato (kg-N/ha/yr)	Waipa (kg-N/ha/yr)
I	13.5	13.5	12	13.5
II	11.5	11	10	11.5
III	8	8.5	9	9
IV	8	8.5	8	9
V	7	7	7	7
VI	6	7	6	7
VII	4	4.5	4	5
VIII	4	4	4	4

Table 10: LUC-Based Allocation Modelling Results: Nitrogen Allocations to Achieve Alternative Freshwater Ecosystem Water Quality targets

LUC Class	Upper Waikato (kg-N/ha/yr)	Middle Waikato (kg-N/ha/yr)	Lower Waikato (kg-N/ha/yr)	Waipa (kg-N/ha/yr)
I	29.7	29.7	26.4	29.7
II	25.3	24.2	22	25.3
III	17.6	18.7	19.8	19.8
IV	17.6	18.7	17.6	19.8
V	15.4	15.4	15.4	15.4
VI	13.2	15.4	13.2	15.4

LUC Class	Upper Waikato (kg-N/ha/yr)	Middle Waikato (kg-N/ha/yr)	Lower Waikato (kg-N/ha/yr)	Waipa (kg-N/ha/yr)
VII	8.8	9.9	8.8	11
VIII	4.4	4.4	4.4	4.4

Figure 3: Land Use Classification (1:50,000) Waikato PC1 Catchment



CONCLUSIONS

42. For this Hearing Stream, and based on my own numerical modelling and analysis, I have presented evidence intended to support decision making associated with potential nitrogen allocation schemes in the Waikato River catchment. I have also presented a new “baseline” model that, I believe, more accurately represents current nitrogen loads and water quality in the catchment.

43. Based on my updated model calibration, I believe that nitrogen attenuation rates were underestimated in the original NIWA model. Based on a review of

available data, I believe both pastoral farm nitrogen export coefficients and dairy land area were also underestimated in the original model. An important implication of this is that the original model underestimated the available load of nitrogen which could be allocated across land uses. This would also have had a significant impact on the economic and scenario modelling and its conclusions.

44. Based on analyses presented here, and in my evidence submitted for Hearing Stream 1, I believe that the proposed long-term nitrogen attribute targets, presented in Table 3.11-1 of the draft Plan Change 1 report (WRC, 2016), are overly ambitious at certain locations (e.g. at Waipapa). I believe that these targets warrant further review.

45. An alternative set of nitrogen concentration targets proposed by B+LNZ, are presented and used here as reference. I have no opinion, one way or the other, with respect to their appropriateness for achieving the long-term strategy and vision in this catchment. I merely present them as informative alternative targets. It is my understanding that these will be investigated further through expert conferencing.

46. It is my opinion that Plan Change 1 should be more prescriptive with respect to laying out a feasible pathway for achieving any final water quality targets. Currently, there appears to be no practical vision for achieving stated goals and this has created significant uncertainty and concern among stakeholders.

47. My modelling has shown that long-term nitrogen targets could be achieved in the basin with an equal allocation of nitrogen export “allowances” across all land use types, even without reductions in point sources, but would require significant land use change. Under such a scheme, the extent of export reduction required by upstream diffuse sources varies widely by location in the basin.

48. Another viable allocation scheme could be based on land use capability classification (LUC), as presented here. Modelling results presented here

quantify LUC-based allocations that could be used to achieve either set of nitrogen concentration targets.

49. Either an equal allocation system or LUC allocation, with trading, could be a viable option for regulating nitrogen in the river basin.

REFERENCES

Waikato Regional Council. 2016. Proposed Waikato Regional Plan Change 1 – Waikato and Waipa River Catchments. December.