

**IN THE ENVIRONMENT COURT
WELLINGTON REGISTRY**

**I TE KŌTI TAIAO O AOTEAROA
TE WHANGANUI-A-TARA ROHE**

UNDER	the Resource Management Act 1991
IN THE MATTER	of appeals under sch 1, cl 14(1) against the decision of Manawatū-Whanganui Regional Council on Plan Change 2 to the One Plan
BETWEEN	TE RUNANGA O RAUKAWA ENV-2021-WLG-20 NGĀTI TURANGA ENV-2021-WLG-21 ANDREW DAY ENV-2021-WLG-22 WELLINGTON FISH AND GAME COUNCIL ENV-2021-WLG-23 Appellants
AND	MANAWATŪ-WHANGANUI REGIONAL COUNCIL Respondent

**STATEMENT OF EVIDENCE OF DR TIMOTHY JASON COX ON BEHALF OF THE
MANAWATŪ-WHANGANUI REGIONAL COUNCIL**

WATER QUALITY MODELLING

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STATEMENT OF EVIDENCE OF DR TIMOTHY JASON COX**A. INTRODUCTION**

- [1] My name is Timothy Jason Cox. I am a water resources engineer and scientist, specialising in water quality and hydrologic modelling. I have over 25 years of experience in water resources science and consulting, with a focus on numerical modelling of freshwater systems.
- [2] I am currently employed by RMA Science and the USA consulting firm CDM Smith. Prior to working for RMA Science, I was employed by Streamlined Environmental. Prior to working for Streamlined Environmental, I was employed by NIWA, where I also performed the bulk of my doctorate research. Prior to that I was employed full time by CDM Smith.
- [3] I hold a Bachelor of Sciences degree in Civil and Environmental Engineering from Duke University (USA), a Master's 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 streams.
- [4] I have developed and applied catchment, stream, and lake water quality models for systems throughout the world, and I have extensive experience in software development. I have published and presented widely in the areas of water resources engineering and science.
- [5] I was engaged by Manawatū-Whanganui Regional Council (**Horizons**) to develop, and apply, catchment nitrogen models for the Manawatū-Whanganui region in support of Proposed Plan Change 2 to the Manawatū-Whanganui One Plan (**PC2**). Through my work, I have read multiple existing scientific reports on water quality in the region, reviewed existing data, and have become generally familiar with the water quality issues in the region.

B. CODE OF CONDUCT

- [6] I confirm that I have read and agree to comply with the Code of Conduct for Expert Witnesses contained in the Environment Court Practice Note 2023. This evidence has been prepared in accordance with that Code. I confirm that I have not omitted to consider material facts that might alter or detract from the opinions that I express. The evidence I am giving is within my area of expertise, except where I state I am relying on the opinion or evidence of other witnesses. I understand it is my duty to assist the Court impartially on relevant matters within my areas of expertise.

C. BACKGROUND

- [7] I participated in the Council-level hearing for PC2, having prepared a s 42A report on the water quality modelling undertaken to support the PC2 provisions. That report focused on the development of catchment nitrogen models for the Manawatū-Whanganui region and the appropriate application of those models for predictive scenario simulations.
- [8] I understand that, following the Government's response to the Overseer peer review report being released, and through expert discussions since lodgement of the appeals on PC2, amendments to the decisions version of PC2 (**DV-PC2**) are proposed. A risk assessment tool is now proposed, as discussed further in the evidence of Dr Jolly and Professor Horne.
- [9] On the basis of discussions with Dr Jolly and Professor Horne, I understand that the risk assessment tool assesses risk of nitrogen leaching on a farm scale basis through a risk scorecard approach, while also accounting for biophysical factors like rainfall and soil type as part of a broader risk matrix. The tool would be used as an alternative to the Overseer-based cumulative nitrogen leaching maximums contained in existing Table 14.2 within the One Plan, and replace the specified nitrogen reduction pathways (20% for pastoral and 35% for commercial vegetable growing (**CVG**)) in the DV-PC2.
- [10] In this evidence, I describe the catchment water quality used to support the original PC2 provisions. I provide this description for reference only. Application results of the original catchment models, and the construction of

those models, is relevant to the evidence presented by my colleague, Dr Ton Snelder.

D. SCOPE OF EVIDENCE

[11] My evidence covers the following matters:

- (a) The development of catchment nitrogen models for the Manawatū-Whanganui region in the context of PC2; and
- (b) The appropriate application of these models for predictive scenario simulations that allow for a comparison of the proposed risk assessment tool with the DV-PC2, with respect to water quality outcomes.

[12] This evidence reviews the matter discussed in my s 42A report for the Council level hearing. This review is relevant to the evidence provided by my colleague, Dr Snelder. In his evidence, he compares the results of new analyses associated with the proposed risk assessment tool to previous catchment modelling results presented in support of the original PC2 provisions. A general understanding of that original modelling is therefore important.

[13] My focus is only on the modelling of nitrogen, which is the contaminant of interest in One Plan Table 14.2 and in the risk assessment tool proposed. Other potential contaminants of interest have not been considered at this time.

[14] In addressing these issues, I have structured my evidence under the following headings:

- (a) An overview of the background science, including sources of nitrogen in the waterways in the Manawatū-Whanganui region, and resultant effects;
- (b) A description of the catchment nitrogen model methods, including a description of the construction of the model;
- (c) A description of the catchment nitrogen model's calibration;

- (d) A discussion of model confidence, uncertainty and appropriate uses; and
- (e) A description of previous model applications relevant to current deliberations.

E. EXECUTIVE SUMMARY

- [15] I led the development of catchment water quality models for the Manawatū-Whanganui region's four major river basins: the Manawatū, the Rangitikei, the Whanganui, and the Whangaehu. The models were designed to investigate the effects of changes in nitrogen discharge from land surfaces (diffuse source discharges) and from point sources on catchment water quality. The models were used in support of PC2 to estimate river and stream nitrogen loads and concentrations under a range of potential management scenarios.
- [16] The models were calibrated, with a focus on quantifying lumped attenuation coefficients, using water quality monitoring data distributed throughout the basins. The process used all relevant data to the extent practical and resulted in close agreement between measured and modelled nitrogen concentrations and loads. Calibrated attenuation coefficient values are supported by a separate independent study of the region. The calibration exercise lends confidence to the application of the models for their intended uses. I consider the models to be well-calibrated.
- [17] All of the water quality experts involved in the Council-level hearing agreed that the modelling approach taken was appropriate for its intended uses, and they were generally satisfied with the model calibration.¹
- [18] In my opinion, the developed models represent the best available science for predicting catchment water quality responses to catchment regulation and are fit for their intended purpose. They also represent an appropriate level of model complexity given the data available and the spatial scale of the analysis.

¹ Joint Witness Statement - Water Quality, 13 August 2020, Annexure A, page 5.

- [19] I also consider that the models developed in this case are suitably transparent for supporting decision making. The lumped parameter approach employed here provides transparency that might be lacking in a more complex, process-based catchment modelling approach. At the same time, the models include enough process complexity and spatial detail to provide for robust assessment of water quality impacts of regulation, as applied in the instance of PC2.
- [20] Sources of model uncertainty have been described. Given these uncertainties, the models are better suited for predicting relative changes in basin water quality rather than absolute values. This type of application effectively negates any underlying bias.
- [21] The application of these models in support of the original PC2 provisions is relevant to the evidence submitted by my colleague, Dr Snelder.

F. BACKGROUND SCIENCE

- [22] Excessive nutrient (nitrogen and phosphorus) runoff from catchment lands causes water quality impairment in receiving waters. Potential impairments include excessive plant and algal growth, colour and clarity degradation, and depressed dissolved oxygen levels.
- [23] It has been established that nutrient impairment, to varying degrees, exists in the Manawatū-Whanganui region. Nitrogen and phosphorus concentrations in the rivers exceed desired target thresholds at many locations. Attached algae (periphyton) also exceed target thresholds during certain times of the year and at certain locations in the basins.
- [24] Known sources of nutrient in the river basins, causing the imbalance in the rivers, include: runoff and sub-surface leaching from pastoral agriculture lands, runoff and sub-surface leaching from horticultural lands, point source industrial discharge, point source municipal wastewater and stormwater discharge, and residential septic tank leaching.
- [25] With respect to pastoral farming and horticulture, fertilizer application, particularly when applied at rates in excess of plant requirements, typically

represents the largest ultimate source of nutrient loading from agriculture. Atmospheric nitrogen fixation by grazed grasses and livestock feed inputs also contribute to the imbalance. Livestock activities contribute to the problem by mobilising the nutrients via grazing/feeding on organic-form nutrient and waste discharge of soluble reactive-form nutrient (often near, or directly to, waterways).

- [26] Intensive farming practices, including dairy farming, horticulture, and irrigated dry stock farms, are known to generate higher nutrient losses, on a per hectare basis, than non-intensive practices. This is primarily attributable to higher stocking rates, higher rates of fertiliser and feed inputs, and the use of irrigation water, compared to non-intensive farming.
- [27] In addition to farm characteristics, other factors that play a role in determining the per unit-area nutrient loss from pastoral farms include: soil type, slope, climate, and sub-surface hydrology.
- [28] At the farm level, as rain falls on fertilised paddocks or arable land, as well as urine patches and manure, nitrogen and phosphorus mass loads are mobilised and transported downgradient via surface runoff and/or infiltration and sub-surface transport. This type of transport and loading to waterways is termed “diffuse” (as opposed to end-of-pipe “point” discharge of municipal and industrial load). Diffuse pathways from pasture to river can be tortuous, resulting in travel/lag times of varying size and, potentially, attenuation of nutrient load. Sources of diffuse-path attenuation include plant uptake, adsorption to soils and substrate, and denitrification. For my purposes here, I use the terms “export” and “discharge” to differentiate between pre-attenuation losses from farm to surface or sub-surface pathways vs. post-attenuation loading to receiving waters, respectively.
- [29] As nutrients are transported downstream in streams and rivers, further attenuation can occur via instream processes such as settling (particulate form), uptake by plant and attached algae, adsorption to bed sediments, and denitrification. This type of attenuation is applicable to both diffuse and point source loads. Attenuation may be increased, in some cases, by water

impoundments (lakes and reservoirs) through enhanced settling, biological activity, and residence time.

- [30] Discussions of catchment nutrient enrichment mitigation options usually start with source control. In general, it is easier to reduce loadings at the source (exports) than to remove nutrient mass from primary waterways.

G. CATCHMENT NITROGEN MODELS: MODEL CONSTRUCTION

- [31] I led the development of catchment water quality models for the Manawatū-Whanganui region's four major river basins: the Manawatū (including the Horowhenua and Coastal Tararua catchments), the Rangitikei, the Whanganui, and the Whangaehu (including the Turakina River catchment). Details of these models are provided in Snelder et al. (2020).
- [32] The models were designed to investigate the effects of changes in nitrogen discharge from land surfaces (diffuse source discharges) and from point sources on catchment water quality. The models can also be used to assess the effects of potential water quality regulation and to test the effectiveness, and feasibility, of mitigation options and strategies. The models were used in support of the original PC2 provisions to estimate river and stream nitrogen loads and concentrations under a range of potential management scenarios.
- [33] The entire region is encapsulated by the four models. The models use sub-catchment export and attenuation coefficients to simulate the generation, transport, and downstream delivery of total nitrogen (**TN**) loads throughout the region.
- [34] As described below, the primary input variables of interest were assumed land use and nitrogen loss rates. The primary outputs of interest to this work were loads and concentrations at reporting locations distributed throughout the river network.
- [35] We developed the models using Streamlined Environmental Limited's Contaminant Allocation and Simulation Model (**CASM**) software. I am the principal developer of the CASM software.

- [36] CASM calculates the generation of a range of user-defined contaminants at a catchment scale and the fate and transport of the contaminants through the catchment's dendritic stream network. Contaminant sources can be defined in CASM as either diffuse (e.g. farms) or point (e.g. municipal discharges). Sources can be aggregated for lower resolution models, including to a sub-catchment scale, or explicitly represented as individual property nodes for higher resolution models.
- [37] Diffuse source contamination calculations follow the widely used "export coefficient" approach, with prescribed areal average mass loading rates ($\text{kg ha}^{-1} \text{ yr}^{-1}$) linked to land use categories and sub-catchment physical and environmental characteristics. Point source loading rates are user defined for each node.
- [38] Three forms of contaminant attenuation are available in the model: diffuse pathway, instream, and lake.
- [39] Note that, for the Horizons models described here, only diffuse pathway attenuation is included. The exception is for two short reaches in the Manawatū River basin. Both export coefficients and attenuation coefficients are prescribed on an annual average basis. Parameter seasonality is not included in the current models. Additionally, no reservoirs are explicitly included in any of the models.
- [40] Each river basin model was subdivided into sub-catchments based on Horizons' Water Management Sub-Zones (**WMSZ**). Each WMSZ is represented in one of the four models. Summaries of each model construct are provided in Table 1.

Table 1: High-level summary of each of the four constructed catchment models.

Model characteristics	Manawatū River	Rangitikei River	Whanganui River	Whangaehu River
Total drainage area (ha)	733,600	401,500	750,400	312,800
Number of WMSZs	50	15	32	15
Total number of diffuse nodes	1425	354	678	327
Number of point sources	22	8	2	5
Number of WQ calibration points	31	7	6	6
Number of explicit tributaries	28	8	12	7

[41] Point source loads were included in the model based on analyses undertaken by Fraser and Snelder (2020). Only point sources with a mean discharge rate of $> 20 \text{ m}^3 \text{ d}^{-1}$ were included in the models. Point source mean annual TN loads were quantified using discharge and concentration data for the period 2007–2017, centred on the 2012 calibration year, described below.

[42] Model diffuse nodes were constructed for each combination of WMSZ, land use capability category, and each of nine land use categories, as described in Snelder et al. (2020a). Each diffuse node was parameterised with a representative export coefficient (derived from Figure 12 of Snelder et al. 2020a) and total land area. Export coefficients were assigned based on values provided by Bright et al. (2018), which vary based on the combination of land use category and each of the four biophysical categories (i.e. climate zone, plant available soil water capacity and whether the land is irrigable and irrigated). Some adjustments were made to Bright et al.'s (2018) export coefficients to account for regionally specific conditions and information and are described in Snelder et al. (2020a). Note that the Bright et al. (2018) export coefficients were derived from the Ministry of Primary Industries database, which in turn was generated using the Overseer model.

H. CATCHMENT NITROGEN MODELS: MODEL CALIBRATION

[43] I calibrated each model so that modelled downstream nitrogen loads and concentrations closely matched measured data for a series of river monitoring stations.

- [44] The primary calibration parameters were diffuse pathway attenuation coefficients, specific to each WMSZ. Calibration proceeded from upstream to downstream with manual adjustments to upstream attenuation coefficients, for each calibration point, to achieve an acceptable agreement in the water quality calibration targets. In a small number of cases, I also adjusted export coefficients, within a plausible range, to achieve an acceptable calibration.
- [45] I used a total of 60 monitoring sites well distributed across the basins to calibrate the models. Measured mean annual loads and concentrations at each site, and associated with the calibration period, were derived from the work of Fraser and Snelder (2020).
- [46] The calibration period “date stamp” was 2012. As noted above, prescribed point source loads and measured calibration targets were directly aligned with this 2012 reference period. Prescribed model export coefficients were generally aligned with this reference period based on the work of Bright et al. (2018).
- [47] Land use data, used to inform the assignment of export coefficients, was based on the best available mapping at the time of model development: a 2008 snapshot. While not ideal, it is my opinion that the use of 2008 land use data for a 2012 calibration period is not problematic. Any changes in land use between 2008 and 2012 are considered to be minimal, with impacts on model parameterisation well within the inherent ranges of model parameter uncertainty.
- [48] Catchment attenuation rates are not expected to change significantly in the future. Therefore, the use of 2012-derived attenuation rates to predict future catchment water quality dynamics is appropriate. This is common practice in modelling.
- [49] The primary objectives of any model calibration exercise are to quantify model calculation parameters that cannot otherwise be readily prescribed, and to increase confidence in model predictions by demonstrating that the model can accurately reproduce historical measured conditions. With respect to the former, this equates to quantifying the least certain parameters in the model, which in this case are the diffuse pathway

attenuation coefficients. With respect to the latter, the process ensures a reliable baseline with which to compare future scenario simulations.

[50] In my opinion, both objectives have been achieved for the models described here. Attenuation coefficients have been rigorously parameterised, using the best available science, and resulting coefficient values, and patterns of values, appear sensible. Further, the calibration exercise lends confidence to the application of the models for their intended uses. I consider the models to be well-calibrated.

[51] Further detail on the model calibration process, and calibration results, can be found in Snelder et al. (2020).

I. MODEL CONFIDENCE, UNCERTAINTY, AND APPROPRIATE USES

[52] In my opinion, the developed models were rigorously calibrated, make use of available data to the extent practicable, represent the best available science for predicting catchment water quality responses to catchment regulation, and are fit for their intended purpose. They also represent an appropriate level of model complexity given the data available and the spatial scale of the analysis.

[53] I have applied the same export coefficient-based modelling approach in support of planning and limit setting for other regional councils, including Waikato Regional Council, Environment Southland, and Taranaki Regional Council.

[54] Relevantly, all attendees of the expert conferencing on Water Quality for the Council level hearing for PC2 agreed with, and supported, the fundamental modelling approach.² There were no major points of contention with respect to the modelling software, construct, or calibration.

[55] I consider that the models are suitably transparent for supporting PC2 decision making. The lumped parameter approach employed here provides transparency that might be lacking in a more complex, process-based catchment modelling approach. At the same time, the models include

² Joint Witness Statement - Water Quality, 28 July 2020, Annexure A, page 8.

enough process complexity and spatial detail to provide for robust assessment of water quality impacts of regulation, as applied in this study.

- [56] That said, there are known uncertainties in the models that, consequently, limit how the models should be used. Sources of uncertainty include the internal model parameterisation and the calibration process, the supporting data sets (e.g. land use data, water quality data, flow data), and the simplified model construct (e.g. lumped attenuation coefficients).
- [57] Attenuation rates are always uncertain in catchment water quality modelling studies. In this case, the attenuation rates are well-supported by a rigorous calibration exercise. Further, the calibrated rates generally agree well with independently derived values for this region (Singh and Elwen 2017). A more detailed discussion of this uncertainty is provided in Snelder et al. (2020a).
- [58] Model uncertainty is unavoidable but must be generally understood in the application of models. In this case, the absolute values of load and concentrations predicted by the models should be regarded as less certain than the relative change. In other words, like most models, these catchment models are better suited for predicting relative changes in basin water quality rather than absolute values. Any underlying model bias is effectively negated through such relative applications.

J. MODEL SCENARIO SIMULATIONS IN SUPPORT OF DV-PC2

- [59] In preparation of PC2, the calibrated catchment models were used to simulate a suite of scenarios, and historical conditions, to identify model sensitivities and to quantify the impacts of potential regulatory pathways associated with PC2. I worked with Dr Snelder to construct and execute these simulations, which were reported on in Snelder et al (2020b).
- [60] Included in that body of work was the simulation of the nitrogen reduction pathway associated with the DV-PC2. For this simulation, I modified baseline nitrogen loss rates for intensive non-consented farmland to match the proposed caps presented in Table 14.2 of the DV-PC2. I assigned non-consented intensive farm leaching rates based on land use capability (LUC)

class associated with each farm parcel, with LUC specific rates provided in Table 14.2.

- [61] The simulation of interest here, as a point of comparison, used the set of 20-year maximum loss rates (i.e. the long term targets). For all consented intensive farm parcels, I assumed the consented nitrogen loss rate for the model simulation. For all non-intensive farm parcels, I retained baseline values as described in Snelder et al (2020a). Further details of this modelling can be found in Snelder et al (2020b).
- [62] This simulation is particularly relevant to the current evidence submitted by my colleague, Dr Ton Snelder. In this evidence Dr Snelder compares changes in nitrogen diffuse loss rates associated with the proposed risk assessment tool to those associated with the simulation I have described above.

6 October 2023

Dr Timothy Jason Cox

K. REFERENCES

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