Memo: Science Technical Advisory Group – Proof of concept model for Essential Freshwater environmental impact assessment

Purpose

The purpose of this memo is to inform the Science Technical Advisory Group (STAG) on the development of an initial prototype model to estimate the environmental impact of the government's proposed freshwater regulations.

Background

The Ministry for the Environment (MfE) is required to advise Cabinet on the impact of the proposed Essential Freshwater regulations through drafting a Regulatory Impact Statement that includes an assessment for how the regulations could impact on the environment. In order to develop a view on the regulation's environmental impact, MfE has developed a modified pollution export coefficient model using published modelled water quality information, LUCAS information and information on farming activity and location.

The prototype model's outputs are presented in this memo for the purpose of sense-checking the utility of the approach only. The purpose was to focus on developing a proof of concept. The model has not yet been thoroughly error checked nor been through a robust peer review with subject matter experts.

The approach and methodology used to develop the model is presented in appendix 1 with technical questions to guide the next phase of development.

Prototype model outputs

The model is designed to show:

- Where across New Zealand are rivers failing river quality bottom lines.
- For failing rivers, how much does the river's pollution exceed the bottom line.
- What industry or human activity is occurring within the river catchments that contribute to the poor water quality.
- What farming pollution mitigations are needed from farms within failing rivers to return rivers to acceptable bottom lines.
- What is the cost of the farm mitigations needed to reverse a river's poor quality.

The modelling results may not reflect how Councils assess attribute state or compliance with the bottom line. Moving beyond a prototype would require the measures and metrics of this work to integrate with the wider literature on water quality.

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An Example: the Ashburton river catchment

Outputs for Canterbury's Ashburton River illustrate the information coming out of the prototype system (Figures 1 and 2 and table 2).

The Ashburton River

The Ashburton River's catchment, for river segments of order 2 and higher, comprises approximately 210 square kilometres of land, 28% of which is associated with Sheep, beef cattle and grain farming, and 60% associated with Dairy farming. The remaining 12% of its catchment is non-farming land, mainly associated with forests and non-farmed grassland. Approximately 0.2 of a square kilometre relates to settlement activity.

Nitrogen pollution characteristics

As a river, the Ashburton is defined by 232 upstream river segments from its sea-end. Its median and 95th percentile Nitrogen-Nitrate (NO_3-N) concentration varies across its length:

Table 1: Distribution of Median and 95th Percentile NO_3-N Concentrations Across Ashburton River

	Median NO_3-N	95th percentile NO_3-N
Minimum	365.4	698.5
25th percentile	1644.9	3538.5
Median	1859.9	3895.9
Mean	1870.8	3833.6
75th percentile	2081.5	4144.0
Maximum	3092.5	5371.6

231 of the Ashburton's segments are National Objectives Framework (NOF) band "D" on STAG's Dissolved Inorganic Nitrogen (mg/L) limits of an annual median > 1.0 mg/L and a 95th percentile > 2.05 mg/L. One segment is band "B".

99.5% of the entire river's length are within NOF band "D" (Table 2)

Table 2: Ashburton River river segment NOF band lengths

Regions	Sea Ending Segment	Total River Length	A	B	C	D
Canterbury Region	13157406	3,109,301	0	17,178.55	0	3,092,122

The mean Nitrogen-Nitrate (NO_3-N) median value across the length of the Ashburton River is 1871 milligrams per cubic meter. Its average 95th percentile nitrogen-nitrate value across its river length is 3,833 exceeding the STAG-recommended *Essential Freshwater* proposed bottom-line of 2,050. In order to get an "C" grade, nitrogen yield from activity with the Ashburton river's catchment needs to reduce by 46%.

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Figure 1: Canterbury Ashburton River

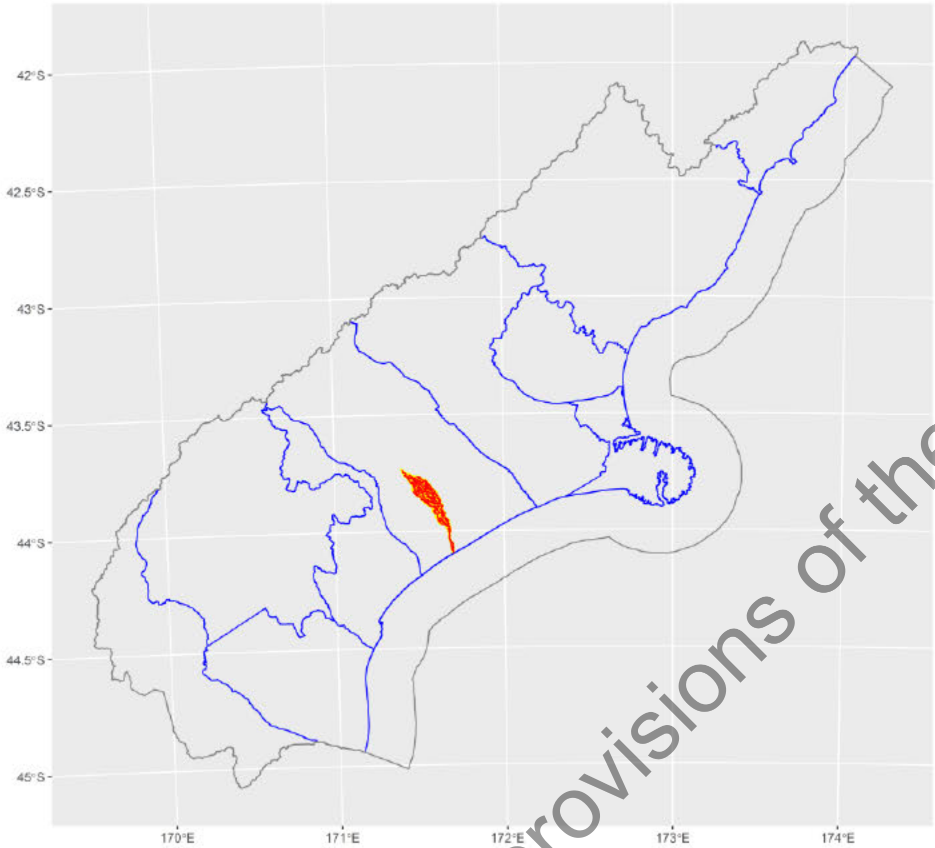

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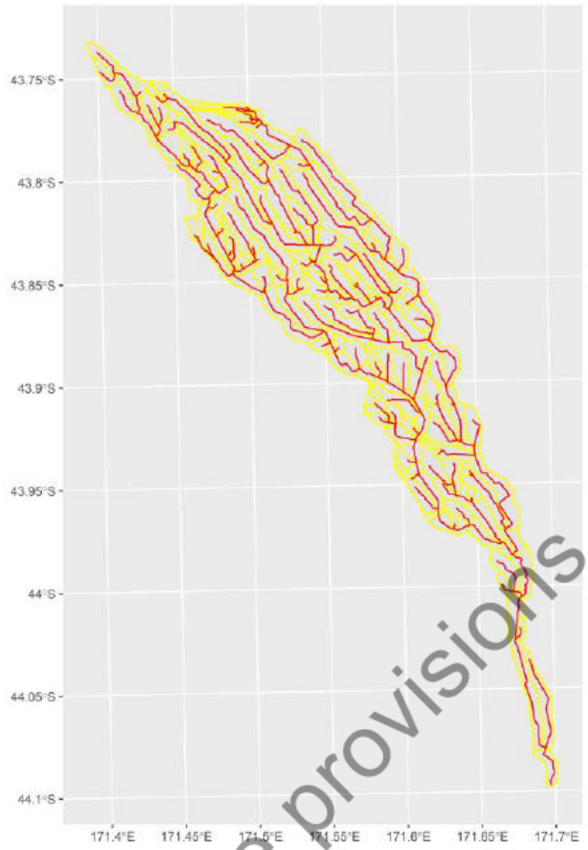
Figure 2: Canterbury Ashburton River – riverlines and catchment



The statistical modelling suggests that for every square kilometre of land high-producing grassland in dairy farming, N03N increases 1.17 percent. The regression also suggests Sheep and Beef farming has a statistically insignificant impact on nitrogen pollution, implying improvements in river quality will be generated entirely from Dairy farming pollution mitigations.

Table 3 below, from Richard McDowell, reflects the range of on-farm mitigations that can be applied to Dairy to reduce nitrogen yield, ranked by increasing cost. McDowell suggests the most cost-effective mitigation strategy is 9(2)(ba)(i) [redacted]

Table 3: Richard McDowell Dairy Mitigations, sorted by increasing cost

9(2)(ba)(i) [redacted]

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Applying the nitrogen mitigations sequentially to Dairy activity within the Ashburton catchment, river pollution is mitigated after the 7th cheapest mitigation is undertaken. Together with the net benefit from the supplementary feeding, implementing strategies to mitigate nitrogen yield ***increases*** dairy farming returns by approximately $6 million per year ***and*** reduces anthropogenic pollution into the Ashburton river back to NOF band "A" levels.

Table 4 Canterbury Ashburton River – Dissolved Inorganic Nitrogen Reductions

Count	nzsegment	NAWI	Strategy	N_Mitigated	Mitigated_Cost	Reduction_Target
1	13157406	AA13_Dairy_cattle_farming	Supplementary feeding with low-N feeds	202.96	-$7,333,728	1,688.14
2	13157406	AA13_Dairy_cattle_farming	Precision agriculture	202.96	-$301,011	1,688.14
3	13157406	AA13_Dairy_cattle_farming	Diuretic supplementation or N modifier	152.22	$41,047	1,688.14
4	13157406	AA13_Dairy_cattle_farming	Change animal type	304.44	$86,199	1,688.14
5	13157406	AA13_Dairy_cattle_farming	Improved N use efficiency	304.44	$340,690	1,688.14
6	13157406	AA13_Dairy_cattle_farming	Bridging sock stream crossings	101.48	$150,506	1,688.14
7	13157406	AA13_Dairy_cattle_farming	Nitrification inhibitors (DCD)	517.55	$837,359	1,688.14
				1,786.07	-$6,178,940	

A limitation of the model is it is incapable of identifying whether any of the Table 2's mitigations are already occurring on Dairy Cattle farms within the Ashburton catchment. We are looking to address this in the next version of the model.

The purpose of Table 4 is to create a check list of pollution mitigation activity that opens a conversation with industry over whether any of the above mitigations are already occurring on the land that directly feeds into New Zealand's most polluted rivers.

Issues for STAG

A lot of new ground was broken in the development of this prototype. The following questions outline the technical input needed to develop the model further.

1. METHODOLOGY: Measurement of a River and the NOF Bands

Is the approach of using an average over the river's length valid?

This paper calculates a mean median value, and a mean 95th percentile across a river's length to identify "how much" a river's total concentration needs to change. The Ashburton River's example is an extreme instance, because almost all of its length is in Band "D".

However, across the regions, the proportion of river's whose mean medians exceed the NOF "D" varies significantly. The bands are designed to be applied to measurement points. They are not a river health measure, as I'm using them.

The median averaging process lowers the extreme measures within components of a river. Applying the NOF bands to the mean medians might not be appropriate; however, no readily usable metric can be easily derived for how much pollution a river needs to lose in order to improve is NOF banding.

With how I'm measuring an entire river, the bands might not be very applicable. I used the measurement bands to make this table of the number of rivers whose mean median or mean 95th percentile was in what band:

	River average Nitrogen Bottom-Line			
	A	B	C	D
Auckland_Region	201	112	120	0
Bay_of_Plenty_Region	82	53	40	0
Canterbury_Region	93	80	46	64
Gisborne_Region	66	15	4	0
Hawkes_Bay_Region	39	43	22	0
Manawatu-Wanganui_Region	8	28	15	0
Marlborough_Region	270	27	11	0
Nelson_Region	15	10	1	0
Northland_Region	459	122	101	0
Otago_Region	32	50	49	2
Southland_Region	758	15	34	1
Taranaki_Region	26	15	35	0
Tasman_Region	99	14	17	0
Waikato_Region	209	68	44	0
Wellington_Region	105	57	14	0
West_Coast_Region	211	14	6	0

We eventually cut this out because it didn't reconcile with our published river quality measures here: https://www.mfe.govt.nz/sites/default/files/media/Fresh%20water/water-quality-state-and-trends-in-nz-rivers.pdf

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Internal staff pointed me to the Cawthron Institute's report on complete river metrics: https://www.mfe.govt.nz/publications/fresh-water/freshwater-biophysical-ecosystem-health-framework.

The Framework recommends the use of standardised methods to facilitate the aggregation of indicator data at several spatial scales (e.g. (sub-) catchment, Freshwater Management Unit, regional and national). Aggregation typically involves averaging, though other statistics might also be used, e.g. the 25th percentile would indicate that 75% of sites are in the specified condition or better. Harmonisation (converting to a common scale) and integration (summing) should happen after spatial aggregation (Department of the Environment and Energy 2017). Data harmonisation standardises the range in metric values from 0 to 1 and renders scores unit-less.

Statistics New Zealand use the second method when they report on the proportion of a river's segments which fail a quality measure.

Therefore, there exist two measures for measuring an entire river's quality: its median/average value, or the proportion of failing segments along its entire river length, and neither are probably directly applicable for estimating how much a river's contamination needs to change through land-based mitigations.

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2. TECHNICAL: Interpretation of regional intercept from the spatial regression
    a. Does the regional intercept reflect historical pollution working itself through the ground water? If it does, then a high regional average value will be persistent over time, but expected to decrease in time as the nitrogen leeches from the groundwater into the river system.

South Island Coefficient	Estimate	Std. Error	z value	Pr(>|z|)
Regions.xCanterbury_Region	6.500750	0.083944	77.44	< 0.0
Regions.xMarlborough_Region	5.844841	0.197662	29.57	< 0.0
Regions.xNelson_Region	6.130845	0.375958	16.31	< 0.0
Regions.xOtago_Region	5.968819	0.081545	73.20	< 0.0
Regions.xSouthland_Region	6.243600	0.103612	60.26	< 0.0
Regions.xTasman_Region	5.968957	0.111404	53.58	< 0.0
Regions.xWest_Coast_Region	6.533552	0.166844	39.16	< 0.0
AA11_Horticulture_and_fruit_growingXXForest -	0.093686	0.058680	-1.5966	0.1103649
AA11_Horticulture_and_fruit_growingXXOther	0.059236	0.065324	0.9068	0.3645072
AA12_Sheep_beef_cattle_and_grain_farmingXXGrassland_High_producing -	0.064510	0.022903	-2.8167	0.0048521
AA12_Sheep_beef_cattle_and_grain_farmingXXGrassland_Low_producing -	0.117818	0.022968	-5.1296	0.000000290418751
AA12_Sheep_beef_cattle_and_grain_farmingXXGrassland_With_woody_biomass	0.045066	0.023968	1.8803	0.0600725
AA12_Sheep_beef_cattle_and_grain_farmingXXWetland -	0.066735	0.072131	-0.9252	0.3548650
AA13_Dairy_cattle_farmingXXForest	0.057573	0.024829	2.3188	0.0204067
AA13_Dairy_cattle_farmingXXGrassland_High_producing	0.147757	0.021552	6.8558	0.000000000007093
AA13_Dairy_cattle_farmingXXGrassland_With_woody_biomass -	0.042378	0.042009	-1.0088	0.3130864
AA21_Forestry_and_loggingXXSettlements -	0.599298	0.322046	-1.8609	0.0627577
AA21_Forestry_and_loggingXXWetland	NA	NA	NA	NA
Not_Farm_AreaXXGrassland_Low_producing -	0.089842	0.024151	-3.7201	0.0001992
Not_Farm_AreaXXOther	0.104980	0.022283	4.7112	0.000002462499503
Not_Farm_AreaXXSettlements	0.041525	0.028965	1.4336	0.1516813
OtherXXForest -	0.109573	0.040742	-2.6894	0.0071571
OtherXXGrassland_High_producing-	0.041211	0.039408	-1.0458	0.2956715
North Island Regression	**Estimate**	**Std. Error**	**z value**	**Pr(>|z|)**
Regions.xAuckland_Region	6.0954818	0.03	175.10	< 0.0
Regions.xBay_of_Plenty_Region	6.0788395	0.05	127.38	< 0.0
Regions.xGisborne_Region	5.4846991	0.1614539	33.97	< 0.0
Regions.xHawkes_Bay_Region	5.8694438	0.0750187	78.24	< 0.0

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Regions.xManawatu-Wanganui_Region	6.1670644	0.0792910	77.78	< 0.0
Regions.xNorthland_Region	5.9153614	0.03	177.68	< 0.0
Regions.xTaranaki_Region	6.5501969	0.05	121.50	< 0.0
Regions.xWaikato_Region	6.1480045	0.05	116.07	< 0.0
Regions.xWellington_Region	5.9162119	0.1014700	58.31	< 0.0
AA12_Sheep_beef_cattle_and_grain_farmingXXForest -	0.0204431	0.0097336	-2.1003	0.035706
AA12_Sheep_beef_cattle_and_grain_farmingXXSettlements -	0.1516477	0.0610530	-2.4839	0.012996
AA13_Dairy_cattle_farmingXXGrassland_High_producing	0.0277611	0.0130639	2.1250	0.033584
AA13_Dairy_cattle_farmingXXGrassland_Low_producing	0.0301799	0.0364050	0.8290	0.407102
AA21_Forestry_and_loggingXXGrassland_High_producing	0.0375208	0.0261049	1.4373	0.150631
Not_Farm_AreaXXForest -	0.0416736	0.0116442	-3.5789	0.000345
Not_Farm_AreaXXGrassland_High_producing -	0.0280268	0.0116172	-2.4125	0.015843
Not_Farm_AreaXXGrassland_Low_producing	0.0396618	0.0187992	2.1098	0.034879
Not_Farm_AreaXXSettlements	0.1001946	0.0131577	7.6149	0.0000000000002642

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Background

In October 2018, the Government established the Essential Freshwater Work Programme, with three objectives:

- Stopping the further degradation and loss of New Zealand's waterways;
- Reversing the past damage; and
- Addressing water allocation issues.

To deliver the objectives the Government established the Essential Freshwater Taskforce (Taskforce) within the Ministry for Environment (MfE). The Taskforce brings together officials from central government agencies and local government to develop policy interventions for the government's consideration.

A programme of research into freshwater regulation impact

In September 2019, the Water Taskforce released a consultation document on policies designed to address the first two of the Government's objectives. The Essential Freshwater policies are out for consultation, and Ministers hope to make their final decisions in the first half of 2020. To support their decision-making, MfE is procuring a programme of research looking at the impact of the proposed regulations on freshwater river quality, and how rivers are used and enjoyed.

Environmental impact report

The first work stream is an Environmental Impact report.

The impact report is an estimate of the impact a range of land-based pollution mitigations have on reducing industry-derived pollution and reversing water quality's declining trend. The environmental impact report draws from the published agricultural science literature on the effectiveness of different pollution mitigation strategies, their costs and their speed of pollution mitigation.

The outputs from this report are a description of the range of agricultural-based pollution mitigations that could be implemented across New Zealand, ranked by cost, mitigation effectiveness and timeframe. Where pollutions mitigation strategies cannot achieve the proposed water quality targets, the Environmental Impact report will identify the size of the proposed land change needed to make the existing pollution mitigations effective.

Scenario-based modelling

Four specific scenarios will be derive from the Environmental Impact Report and "flow through" the remaining reports:

1. Baseline / Status Quo: Under the baseline, the existing National Policy Statement on Freshwater (NPSFW) 2017 only applies. Assumptions will be made about implementation timeframes in order to operationalise the modelling.

2. NPSFW 2020 only: This scenario assumes higher water quality thresholds are applied, but Councils are still free to choose the duration of the quality achievement.

3. The cheapest mitigations applied regionally: Under this scenario, if only the cheapest mitigations are required what would the total mitigations cost?

4. The most effective mitigations applied regionally: If the most effective mitigations are implemented what would they cost?

What does the modelling show

The modelling is designed to identify average pollution across New Zealand's rivers, and where spatially, are the most polluted rivers located. Estimates of water quality for the river are generated from taking a weighted average of the published modelled water quality measures for each upstream river, weighted by the river segment's length. The outcome of that calculation is an estimate of the river's mean median and 95th quartile pollution levels.

The river's relationship to the *Essential Freshwater* bottom line is derived from the overall averaged river median's and average river 95 percentile values. The two quality measures from the published proposed bottom line metrics are generated from the weighted average of the upstream segments and is used to gauge the extent of pollution yield that needs to be mitigated from the land-based activity.

The modelling captures the volume of land within each river's catchment and decomposes that total area into industries or non-industry land use. Presently, the industry and land use metrics are restricted to land area only, although the intention is to extend the metrics to include an estimate of the value of GDP generated by industries operated within the catchment regions to give a better measure of scale of activity occurring within the river's catchment.

Against the proposed bottom-line, the impact modelling successively implements pollution mitigations, sourced from the agriculture research literature. Richard McDowell[1], Chief Scientist with Our Land and Water, supplied the mitigation strategies, their average costs and their average effectiveness for mitigating different sources of pollution.

Using McDowell's mitigation strategies, and the difference between measured pollution and the proposed bottom-line, the model incrementally models the impact of each successive strategy applied to the land area within the catchment. From each mitigation strategy's application, an estimate of the mitigated pollution is generated. The costs of the mitigation are expressed as dollars per kilogram of pollution mitigated per hectare of farmed land per year.

How was the modelling undertaken?

Spatial analysis and spatial regression provided the foundation for the modelling. Spatial data and spatial intersection and area measures were used to create a statistical data source for a North Island / South Island specific dataset of industry activity, land types and river quality measures.

An island-specific spatial error regression model was estimated to connect the different land use/activity measures back to river pollution. Initial statistical analysis suggested early regressions suffered from severe auto-correlation. Local differences in soil-quality, rainfall and attenuation across different areas meant rivers closer to each other are more similar than rivers further away from each: the cause of the auto-correlation within the early regressions.

[1] https://www.researchgate.net/profile/Rich Mcdowell

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Spatial error regression models the spatial nature of the autocorrelation within the regression error term, generating unbiased estimates of the relative contributions of different farm activity and farm uses. The river catchment geometries themselves served as the spatial weights matrix for the spatial modelling.

The input data sources were:

a. The River Environment Classification (version 2) (REC) was used to capture the spatial location of all rivers of order 2 and above across New Zealand.
b. The associated REC watershed spatial boundaries were used to spatially map all land areas whose underlying activity directly affected the water quality of a sea-ending river
c. AgriBase spatial geometries on agricultural producers
d. LUCAS spatial geometrics on land use across New Zealand
e. MfE's published River water quality modelled state 2013–2017
f. Richard McDowell's pollution mitigation strategies

Next steps

The modelling has been set up for future extensions. Specifically, AgriBase farms have been coded to Statistics New Zealand's National Accounts Working Industry (NAWI) groupings, providing a natural extension for introducing Gross Domestic Product-type measures into the modelling of farm activity and its relationship to pollution.

Working at the NAWI industry level, means the analysis inherits farm input and output pricing information from Statistics New Zealand price indices. As the relative Producer Price Index output prices for different forms of agriculture activities change in the future, long-term changes in price relativities should drive aspects of land use change. In the future, capital stock, investment and other nationally derived measures of agriculture production and change might potentially be introduced into the modelling.

The modelling also inherits MfE's LUCAS land use mapping, providing another perspective on land-use change, especially around agricultural intensification and deforestation. In combination with Statistics New Zealand's price metrics, the modelling has the potential for decomposing changes in the environment into regulatory-based drivers (like national policy statements), versus commercial drivers related to profitability.

Other questions to be addressed before release:

1. TECHNICAL: The relationship between water pollution and river type. The model departs from traditional regression analysis that incorporates REC soil type measures, for the reason that it's unclear how to create a weighted average soil type measure together with the weighted average river quality. Through employing spatial regression, much of the soil type effects will be captured through modelling the aggregate spatial autocorrelation between river catchments.

2. TECHNICAL: Missing E.Coli and sediment "bottom-lines" and general river-level measures of health (note work from Cawthron Institute). E.Coli is measured at specific sites, not lending itself to a river-based methodology like developed.

   Secondly, the Cawthron Institute has done some work on aggregate river-based water quality measures. Should their river-quality methodology be adopted?

3. METHODOLOGICAL: Basic error checking
   The work has not yet been through basic error checking, the result of delivering it to a very tight timeframe. Please expect some aspects of the results to change as errors are discovered.

4. TECHNICAL: Spatial regression validity
   The spatial regression methodology will be peered reviewed by Sarah Crichton within The Treasury.

5. TECHNICAL: Other farm-level pollution mitigations
   Richard McDowell's work did not extend to mitigations for horticultural-based pollution, nor forestry-base pollution. Information on forestry and horticultural specific pollution

mitigations could extend the mitigation options in this work.

6. METHODOLOGICAL: Exceptions and "natural" levels of contamination
   Where a river's "natural" bottom-line exceeds the *Essential Freshwater* proposed bottom line, then policy options exist that mean a river could receive an exemption. However, tied up with the notion of what does the spatial-regression intercept represent, is a question about how does the natural levels of contamination change.

7. TECHNICAL: Treatment of water quality measures as "quantities" – is this valid?