Research Memorandum:

Estimating phosphorus concentrations according to landuse (and likely change) in streams and rivers of the Lake Rotorua catchment

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Aim

To model the likely median filtered reactive phosphorus (FRP; *viz*. analogous to dissolved reactive P) and total phosphorus (TP) concentrations with the percentage of intensive agricultural landuse in the Lake Rotorua catchment. These data can be used by the Bay of Plenty Regional Council to determine likely effects (on median concentrations) of shifting landuse from intensive agriculture to non-intensive landuses.

Materials and Methods

Data sources, classification and initial filters

A database containing water quality data representing several analytes was collated from McDowell et al. (2009) and the National River Water Quality Network (NRWQN). This database included about 1000 sites sampled by Regional Authorities and 77 sampled by the National Institute of Water and Atmospheric Research. Data from 1989 to 2009 was used. Spatial and temporal coverage varied despite the large size of the dataset. For instance, sampling frequencies vary from fortnightly to bimonthly. The sites in our dataset also tended to represent locations where Regional Authorities were either investigating a possible change in water quality or were likely to quickly reflect any change in, for example, land use.

Fig. 1. Location of filtered sampling sites (n = 768) within New Zealand by region.

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The New Zealand river environment classification (REC; Snelder and Biggs, 2002; Table 1) was used to classify the sites according to the environmental conditions that are strong determinants of their baseline water quality. Site geographic co-ordinates and names were used to identify the REC class at the first three levels (climate, topography, and geology) for the segments on which each site was located. The proportion of the area contributing catchment in categories defined by the New Zealand Land Cover Database (MFE 2004) were also obtained for each segment from the REC database. Previous work by Unwin et al. (2010) identified the percentage of intensive agriculture (originally listed by Unwin et al. (2010) as heavy pasture, due to the dominance of high producing exotic grassland, but also included small areas of cropland, vineyards, orchards) or urban land cover as the land uses with the most important predictors of water quality. Ten sites had a high proportion of urban land use and were excluded from further analysis. In addition, sites were only included in the database if there were 15 or more observations during the period of record, to ensure accurate estimates of median values for each variable at each site. Furthermore, values below the indicated detection limit were set at half the detection limit. The proportion was < 1% for TP, but 4.3% for FRP;

Table 1. Defining characteristics, categories, and membership criteria of the River Environment Classifications at the first three levels.

Defining characteristic	Categories	Notation	Category membership criteria
Climate	Warm-extremely-wet	WX	Warm: mean annual temperature ≥ 12°C
	Warm-wet	WW	Cool: mean annual temperature < 12°C
	Warm-dry	WD	Extremely Wet: mean annual effective precipitation[1] ≥ 1500 mm
	Cool-extremely-wet	CX	Wet: mean annual effective precipitation > 500 and < 1500 mm
	Cool-wet	CW	Dry: mean annual effective precipitation ≤ 500mm
	Cool-dry	CD	
Topography	Glacial-mountain	GM	M and % permanent ice > 1.5%
	Mountain	M	> 50% annual rainfall volume above 1000m ASL
	Hill	H	50% rainfall volume between 400 and 1000m ASL
	Low-elevation	L	50% rainfall below 400 m ASL
	Lake	Lk	Lake influence index[2] > 0.033
Geology	Alluvium	Al	Category = the spatially dominant geology category unless
	Hard sedimentary	HS	combined Soft-Sedimentary geological categories exceed 25% of
	Soft sedimentary	SS	catchment area, in which case class = SS.
	Volcanic acidic	VA	

[1] Effective precipitation = annual rainfall – annual potential evapotranspiration
[2] See Snelder and Biggs (2002) for a description.

Sites were not equally distributed amongst REC classes (Figure 1). To decrease this imbalance, we amalgamated the sites in the glacial mountain topography category of the REC into the mountain category. There were relatively few sites in these categories (*c*. 10 and 20, respectively) and because these two categories represent similar environmental mountainous catchment conditions, water quality can be expected to be similar (Larned et al., 2003).

Statistical analysis

A full explanation of the methodology used in this approach can be found in McDowell et al. (2013). Sites were treated as independent data and values at each site were represented by medians for each analyte. Some 20 out of the 768 filtered sites used in the analysis were located on the same river segment, but as this represents only 2% of sites it is not expected to bias the analysis. Medians of each analyte were log (base 10) transformed before analysis.

A mixed-effects model was used with random slopes and intercepts, and with a smoothing spline (Verbyla et al., 1999), to model the relationship between the logged median values of each analyte and the percent intensive agriculture. The benefit of including a spline in the mixed-effects model is that it represents some non-linearity in the relationship. The benefit of fitting the random terms is that some information is gleaned from the data on all classes to aid the estimation on each class.

Where a class has little data, the data from the other classes becomes more important and pulls the individual class estimate towards the mean of the other classes. However, a class with sufficient data for estimating the intercept will not be noticeably affected by the data from the other classes. Hence a mixed-effects model means that data from classes with few data are not discarded.

REC classes at the second level (climate by topography) with the largest number of sites (i.e. cool-dry hill, cool-dry lowland, cool-wet hill, cool-wet lowland, cool-extremely wet hill, cool-extremely wet lowland, warm-dry lowland and warm-wet lowland) were further analysed (as above) sites grouped at the third (climate by topography by geology) level of the REC provided there were 5 or more sites within each geology class (alluvial, hard sedimentary, soft sedimentary and volcanic acid).

The uncertainty of estimated reference conditions (i.e. the intercepts) is a reflection of the strength of the relationship between the analyte and percent intensive agriculture and the number of contributing sites. This was determined by the width of the 90% confidence intervals of the intercept terms in the models.

The models were fitted in Genstat 12 (Genstat committee, 2010) using residual maximum likelihood.

Model outputs

There were nine distinct REC classes within the Lake Rotorua catchment (CW/H/VA; CW/L/VA; CW/Lk/VA; WW/H/VA; WW/L/M; WW/L/SS; WW/L/VA; WW/Lk/M; WW/Lk/VA). Modelled outputs for the estimated median FRP and TP concentrations with increasing percent intensive agricultural landuse are given in Appendix I for each class. An example output is given for one class in Figure 2. Due to insufficient data (< 15 observations at each site) the CW/Lk/VA, WW/H/VA, WW/L/M and WW/Lk/VA classes were estimated using data at the 2nd level of the REC.

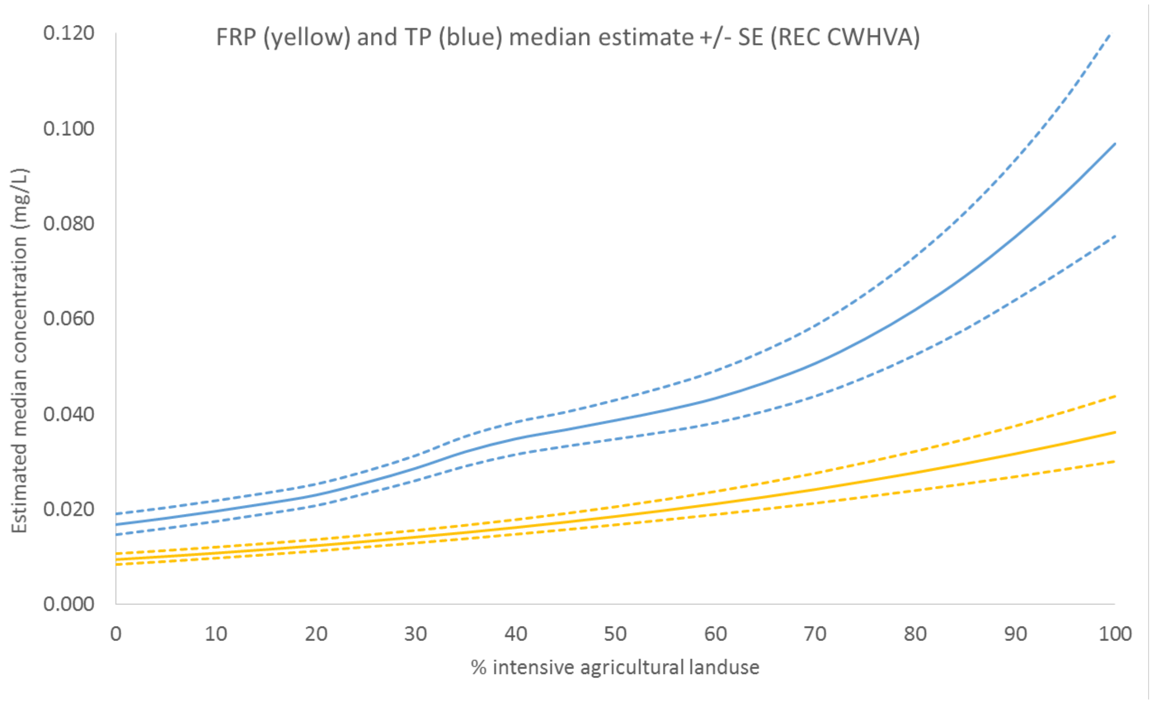

Figure 2. Estimated median FRP and TP concentrations for sites in New Zealand classified as having a cool wet climate, hill topography, and volcanic acid geology.

Comparisons are made for sites on nine streams draining into Lake Rotorua between the measured median FRP and TP concentrations (Scholes, 2013) for 1992 to 2012 and predicted (+/- standard errors) concentrations (Table 2). Measured concentrations were within the range predicted (median +/- standard error) in all but two cases (both FRP). This is a better performance (89% frequency of fit) than use of the model to predict reference conditions, nationally at the climate-source of flow level of the REC for a wide range of water quality analytes (81%) as found in McDowell et al. (2013).

Although outputs in Tables 1 and 2 of the Appendix can be used to estimate median FRP and TP concentrations according to landuse and potentially - landuse change, these predictions refer to systems in a steady state (i.e. equilibrium). As such, lag times associated with the legacy of past landuse will not be accounted for. Significant lag times will slow the response of the catchment and impair the ability of the predictive model to derive accurate estimates.

Table 2. Landuse (taken from AgriBase - 2015), river environment classification (climate-source of flow-geology) and measured (1992-2012) and predicted median FRP and TP concentrations (mg/L) +/- standard error (SE) for regularly monitored sites on streams in the Lake Rotorua catchment.

Catchment	X_NZTM	Y_NZTM	REC (CSOFG)	% Intensive Ag. Land[1]	------------------------ FRP ------------------------				------------------------ TP ------------------------				FRP Fit	TP Fit
					Median	Predicted Med	Median - SE	Median + SE	Median	Predicted Median	Median - SE	Median + SE		
Awahou	1886312.351	5772441.028	CW/H/VA	60	0.065	0.021	0.019	0.024	0.069	0.043	0.038	0.049	no	**yes**
Hamurana	1884058.393	5774929.305	WW/H/VA	63	0.080	0.015	0.009	0.023	0.083	0.034	0.023	0.049	no	**yes**
Ngongotaha	1890163.124	5775346.740	CW/H/VA	54	0.028	0.020	0.018	0.022	0.047	0.041	0.036	0.046	**yes**	**yes**
Puarenga	1883374.346	5777229.930	CW/L/VA	44	0.037	0.026	0.021	0.031	0.068	0.057	0.046	0.070	**yes**	**yes**
Utuhina	1891597.654	5780083.409	CW/H/VA	70	0.039	0.024	0.021	0.028	0.063	0.051	0.044	0.059	**yes**	**yes**
Waingaehe	1881941.056	5780318.949	CW/L/VA	97	0.093	0.046	0.036	0.059	0.112	0.112	0.085	0.148	**yes**	**yes**
Waiohewa	1881433.446	5781360.344	CW/Lk/VA	62	0.019	0.020	0.014	0.028	0.069	0.036	0.028	0.046	**yes**	**yes**
Waiowhero	1882062.659	5783857.487	CW/L/VA	96	0.036	0.044	0.035	0.055	0.048	0.103	0.079	0.133	**yes**	**yes**
Waiteti	1886150.975	5785357.048	CW/H/VA	69	0.031	0.024	0.021	0.028	0.046	0.051	0.044	0.059	**yes**	**yes**

[1] Urban landuse in the Utuhina and Waingaehe streams included as intensive agricultural landuse. However, as the model does not include urban landuse, estimates should be treated with caution.

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Appendix I

Table 1. National estimates (+/- standard error) of the median FRP concentration (mg P/L) at 5% intervals of intensive agricultural landuse by REC class. Only those streams and rivers found in the Lake Rotorua catchment are given.

% intensive landuse	CW/H/VA	CW/L/VA	CW/Lk/VA	WW/H/VA	WW/L/M	WW/L/SS	WW/L/VA	WW/Lk/M	WW/Lk/VA
Medians									
0	0.009	0.016	0.002	0.008	0.009	0.007	0.010	0.032	0.032
5	0.010	0.017	0.002	0.008	0.010	0.007	0.010	0.029	0.029
10	0.011	0.017	0.003	0.009	0.010	0.007	0.011	0.027	0.027
15	0.012	0.018	0.003	0.009	0.011	0.008	0.011	0.025	0.025
20	0.012	0.019	0.004	0.010	0.011	0.008	0.012	0.023	0.023
25	0.013	0.021	0.005	0.010	0.012	0.009	0.013	0.021	0.021
30	0.014	0.022	0.006	0.011	0.012	0.009	0.013	0.020	0.020
35	0.015	0.023	0.008	0.012	0.013	0.010	0.014	0.019	0.019
40	0.016	0.024	0.010	0.013	0.014	0.010	0.015	0.018	0.018
45	0.017	0.026	0.012	0.014	0.015	0.011	0.016	0.016	0.016
50	0.019	0.027	0.015	0.014	0.015	0.011	0.017	0.015	0.015
55	0.020	0.028	0.017	0.014	0.015	0.012	0.018	0.013	0.013
60	0.021	0.030	0.020	0.014	0.015	0.013	0.019	0.011	0.011
65	0.023	0.032	0.024	0.015	0.015	0.014	0.020	0.010	0.010
70	0.024	0.033	0.029	0.015	0.016	0.014	0.021	0.009	0.009
75	0.026	0.035	0.036	0.017	0.017	0.015	0.022	0.009	0.009
80	0.028	0.037	0.046	0.018	0.019	0.016	0.023	0.008	0.008
85	0.030	0.039	0.060	0.020	0.021	0.017	0.024	0.008	0.008
90	0.032	0.041	0.079	0.023	0.023	0.018	0.026	0.008	0.008
95	0.034	0.044	0.094	0.024	0.024	0.019	0.027	0.007	0.007
100	0.036	0.046	0.099	0.021	0.021	0.020	0.029	0.006	0.006
Medians - SE									
0	0.008	0.012	0.001	0.005	0.008	0.005	0.008	0.019	0.019
5	0.009	0.013	0.002	0.005	0.008	0.006	0.009	0.018	0.018
10	0.010	0.014	0.002	0.006	0.009	0.006	0.009	0.017	0.017
15	0.010	0.015	0.003	0.006	0.009	0.007	0.010	0.017	0.017
20	0.011	0.016	0.004	0.007	0.010	0.007	0.011	0.016	0.016
25	0.012	0.017	0.004	0.008	0.010	0.008	0.011	0.015	0.015
30	0.013	0.018	0.005	0.008	0.011	0.008	0.012	0.015	0.015
35	0.014	0.019	0.007	0.009	0.012	0.009	0.013	0.014	0.014
40	0.015	0.020	0.008	0.010	0.013	0.009	0.014	0.014	0.014
45	0.016	0.021	0.010	0.010	0.014	0.010	0.014	0.013	0.013
50	0.017	0.022	0.011	0.010	0.014	0.010	0.015	0.011	0.011
55	0.018	0.023	0.013	0.010	0.014	0.011	0.016	0.010	0.010
60	0.019	0.024	0.014	0.009	0.014	0.011	0.017	0.009	0.009
65	0.020	0.026	0.016	0.009	0.014	0.012	0.018	0.007	0.007
70	0.021	0.027	0.019	0.009	0.015	0.013	0.019	0.007	0.007
75	0.023	0.029	0.023	0.009	0.015	0.013	0.020	0.006	0.006

80	0.024	0.030	0.028	0.010	0.017	0.014	0.021	0.006	0.006
85	0.025	0.031	0.035	0.010	0.018	0.015	0.022	0.005	0.005
90	0.027	0.033	0.045	0.011	0.020	0.015	0.023	0.005	0.005
95	0.028	0.035	0.051	0.010	0.020	0.016	0.024	0.004	0.004
100	0.030	0.036	0.052	0.009	0.018	0.017	0.025	0.003	0.003
Medians + SE									
0	0.011	0.020	0.003	0.013	0.011	0.008	0.011	0.055	0.055
5	0.011	0.021	0.003	0.013	0.011	0.008	0.012	0.047	0.047
10	0.012	0.022	0.003	0.013	0.012	0.009	0.012	0.042	0.042
15	0.013	0.023	0.004	0.013	0.012	0.009	0.013	0.037	0.037
20	0.014	0.024	0.005	0.014	0.013	0.009	0.014	0.033	0.033
25	0.015	0.026	0.006	0.014	0.013	0.010	0.014	0.029	0.029
30	0.016	0.027	0.008	0.015	0.014	0.010	0.015	0.026	0.026
35	0.017	0.028	0.010	0.016	0.015	0.011	0.016	0.024	0.024
40	0.018	0.030	0.012	0.017	0.015	0.012	0.017	0.022	0.022
45	0.019	0.031	0.015	0.018	0.016	0.012	0.017	0.020	0.020
50	0.021	0.033	0.019	0.020	0.016	0.013	0.018	0.018	0.018
55	0.022	0.035	0.023	0.021	0.016	0.014	0.019	0.016	0.016
60	0.024	0.037	0.028	0.022	0.016	0.014	0.021	0.015	0.015
65	0.026	0.039	0.034	0.023	0.017	0.015	0.022	0.014	0.014
70	0.028	0.041	0.044	0.026	0.018	0.016	0.023	0.013	0.013
75	0.030	0.043	0.057	0.030	0.019	0.017	0.024	0.013	0.013
80	0.032	0.046	0.075	0.034	0.021	0.018	0.026	0.013	0.013
85	0.035	0.049	0.101	0.041	0.023	0.020	0.028	0.013	0.013
90	0.037	0.052	0.139	0.049	0.027	0.021	0.029	0.014	0.014
95	0.040	0.055	0.173	0.053	0.027	0.022	0.031	0.013	0.013
100	0.044	0.059	0.190	0.051	0.025	0.024	0.034	0.010	0.010

Table 2. National estimates (+/- standard error) of the median TP concentration (mg P/L) at 5% intervals of intensive agricultural landuse by REC class. Only those streams and rivers found in the Lake Rotorua catchment are given.

% intensive landuse	CW/H/VA	CW/L/VA	CW/Lk/VA	WW/H/VA	WW/L/M	WW/L/SS	WW/L/VA	WW/Lk/M	WW/Lk/VA
Medians									
0	0.017	0.033	0.009	0.012	0.019	0.021	0.016	0.033	0.033
5	0.018	0.035	0.010	0.014	0.020	0.023	0.017	0.035	0.035
10	0.020	0.037	0.011	0.015	0.022	0.024	0.018	0.038	0.038
15	0.021	0.039	0.013	0.016	0.023	0.026	0.020	0.040	0.040
20	0.023	0.041	0.014	0.017	0.025	0.027	0.021	0.042	0.042
25	0.026	0.044	0.016	0.019	0.027	0.030	0.024	0.045	0.045
30	0.029	0.048	0.019	0.021	0.030	0.033	0.027	0.050	0.050
35	0.032	0.052	0.023	0.025	0.034	0.037	0.030	0.056	0.056
40	0.035	0.055	0.026	0.027	0.037	0.039	0.032	0.059	0.059
45	0.037	0.057	0.028	0.028	0.038	0.041	0.034	0.061	0.061
50	0.039	0.058	0.031	0.029	0.039	0.042	0.036	0.061	0.061
55	0.041	0.060	0.033	0.030	0.040	0.044	0.038	0.062	0.062
60	0.043	0.062	0.036	0.031	0.041	0.046	0.040	0.063	0.063
65	0.047	0.065	0.040	0.034	0.044	0.049	0.043	0.067	0.067
70	0.051	0.069	0.046	0.037	0.048	0.053	0.047	0.072	0.072
75	0.056	0.074	0.054	0.042	0.054	0.057	0.051	0.079	0.079
80	0.062	0.080	0.065	0.048	0.061	0.063	0.057	0.089	0.089
85	0.069	0.086	0.078	0.056	0.069	0.069	0.063	0.100	0.100
90	0.077	0.094	0.094	0.065	0.080	0.076	0.071	0.114	0.114
95	0.086	0.103	0.102	0.068	0.083	0.084	0.079	0.116	0.116
100	0.097	0.112	0.100	0.063	0.076	0.093	0.088	0.106	0.106
Medians - SE									
0	0.015	0.024	0.007	0.009	0.016	0.017	0.013	0.023	0.023
5	0.016	0.026	0.008	0.010	0.017	0.018	0.015	0.025	0.025
10	0.018	0.028	0.010	0.011	0.019	0.020	0.016	0.027	0.027
15	0.019	0.030	0.011	0.012	0.021	0.021	0.017	0.030	0.030
20	0.021	0.032	0.012	0.013	0.022	0.023	0.019	0.032	0.032
25	0.023	0.035	0.014	0.014	0.024	0.026	0.021	0.034	0.034
30	0.026	0.038	0.017	0.016	0.027	0.028	0.024	0.039	0.039
35	0.029	0.042	0.020	0.018	0.031	0.032	0.027	0.044	0.044
40	0.032	0.045	0.022	0.020	0.034	0.034	0.029	0.047	0.047
45	0.033	0.046	0.023	0.021	0.035	0.036	0.031	0.048	0.048
50	0.035	0.048	0.025	0.021	0.036	0.038	0.033	0.048	0.048
55	0.036	0.049	0.026	0.022	0.037	0.039	0.034	0.049	0.049
60	0.038	0.050	0.028	0.022	0.038	0.041	0.036	0.050	0.050
65	0.041	0.053	0.030	0.023	0.041	0.043	0.039	0.052	0.052
70	0.044	0.056	0.034	0.025	0.044	0.046	0.042	0.055	0.055
75	0.048	0.059	0.039	0.028	0.049	0.050	0.046	0.060	0.060
80	0.052	0.064	0.046	0.031	0.055	0.054	0.050	0.065	0.065
85	0.058	0.068	0.053	0.035	0.062	0.059	0.056	0.072	0.072

90	0.064	0.074	0.063	0.040	0.070	0.064	0.061	0.080	0.080
95	0.071	0.079	0.067	0.040	0.073	0.070	0.068	0.080	0.080
100	0.077	0.085	0.063	0.037	0.067	0.075	0.074	0.071	0.071
Medians + SE									
0	0.019	0.045	0.011	0.018	0.022	0.027	0.019	0.048	0.048
5	0.020	0.047	0.012	0.019	0.023	0.028	0.020	0.050	0.050
10	0.022	0.048	0.013	0.020	0.025	0.029	0.021	0.052	0.052
15	0.024	0.050	0.015	0.022	0.026	0.031	0.023	0.054	0.054
20	0.025	0.052	0.017	0.023	0.028	0.033	0.024	0.056	0.056
25	0.028	0.056	0.019	0.025	0.029	0.035	0.027	0.059	0.059
30	0.031	0.060	0.022	0.029	0.033	0.039	0.030	0.064	0.064
35	0.035	0.065	0.027	0.033	0.038	0.043	0.033	0.072	0.072
40	0.038	0.069	0.031	0.036	0.040	0.045	0.036	0.075	0.075
45	0.040	0.070	0.034	0.038	0.041	0.046	0.037	0.076	0.076
50	0.043	0.072	0.038	0.040	0.042	0.048	0.039	0.077	0.077
55	0.046	0.074	0.041	0.042	0.043	0.050	0.041	0.079	0.079
60	0.049	0.076	0.046	0.045	0.045	0.052	0.044	0.081	0.081
65	0.053	0.080	0.053	0.049	0.048	0.055	0.048	0.086	0.086
70	0.059	0.085	0.063	0.055	0.053	0.060	0.052	0.095	0.095
75	0.065	0.092	0.075	0.064	0.059	0.066	0.057	0.106	0.106
80	0.073	0.100	0.091	0.075	0.067	0.072	0.064	0.120	0.120
85	0.082	0.109	0.113	0.088	0.077	0.080	0.072	0.138	0.138
90	0.093	0.120	0.140	0.106	0.090	0.090	0.081	0.161	0.161
95	0.106	0.133	0.157	0.114	0.094	0.101	0.092	0.169	0.169
100	0.121	0.148	0.157	0.109	0.087	0.114	0.105	0.157	0.157