Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Date: 4/7/17

MEMORANDUM

FROM: ZEB ETHERIDGE

TO: FILE
cc

SUBJECT: Waimakariri Groundwater Model – Variography

Background

This memo provides variograms which will be used in the above model as a basis for interpolation of hydraulic conductivity in the x and y directions. The variograms aim to quantify the rate of lateral variance in hydraulic conductivity and the large scale x,y anisotropy of the aquifer system, so that this information can be incorporated into the model optimisation process. The model groundwater flow (and advective transport) direction will then account for both the hydraulic gradient direction and the horizontal anisotropy[1]. The variography study area comprises the model domain shown in Figure 2.

Method

I have used two sources of hydraulic conductivity data: transmissivity (T) values from aquifer test analysis and specific capacity (SC) data. Both of these data sets have some limitations:

The T data are a mixture of tests types (step test = 60% of data set, constant rate pumping tests = 40%), test quality ratings (low to high) interpretation methods, aquifer conditions (leaky, confined, possible boundary conditions) and interpretation requirements (e.g. tests undertaken for well interference usually interpreted to determine lowest [most conservative] T value). The T data set is heavily biased towards the most transmissive parts of the system, since wells are screened at depths where the highest yield is encountered, and wells which do not encounter sufficiently high yielding strata will not be tested. Pumping tests are not normally undertaken on wells that fall within permitted activity rules (domestic and stockwater).

Specific capacity values are a function of several factors including aquifer transmissivity, well losses, pumping rate and pumping duration. Well loss rates are affected by drilling method, well design, well development and near-field hydraulic conductivity. Although SC data are also strongly biased towards the more transmissive parts of the aquifer, the bias is less pronounced than that in the aquifer test data because well yield data are often recorded even when well yields are very low (e.g. domestic wells only require low yields and hence SC values are recorded even where lower yielding strata are screened).

Despite these issues there is a reasonable positive correlation between log transformed SC and T data (Figure 1). Part of the scatter around the regression line relates to issues with the

[1] Horizontal - vertical anisotropy and vertical hydraulic gradient will also be incorporated into the model based on other data not discussed in this memo

T data, and part is due to those components of the specific capacity values which are unrelated to aquifer properties.

The chief advantage of the specific capacity data is resolution: we have over 7,000 specific capacity values within the model domain but only 700 T values over an area of around 343,000 ha. I have therefore predominantly used SC data to quantify spatial variance of hydraulic conductivity.

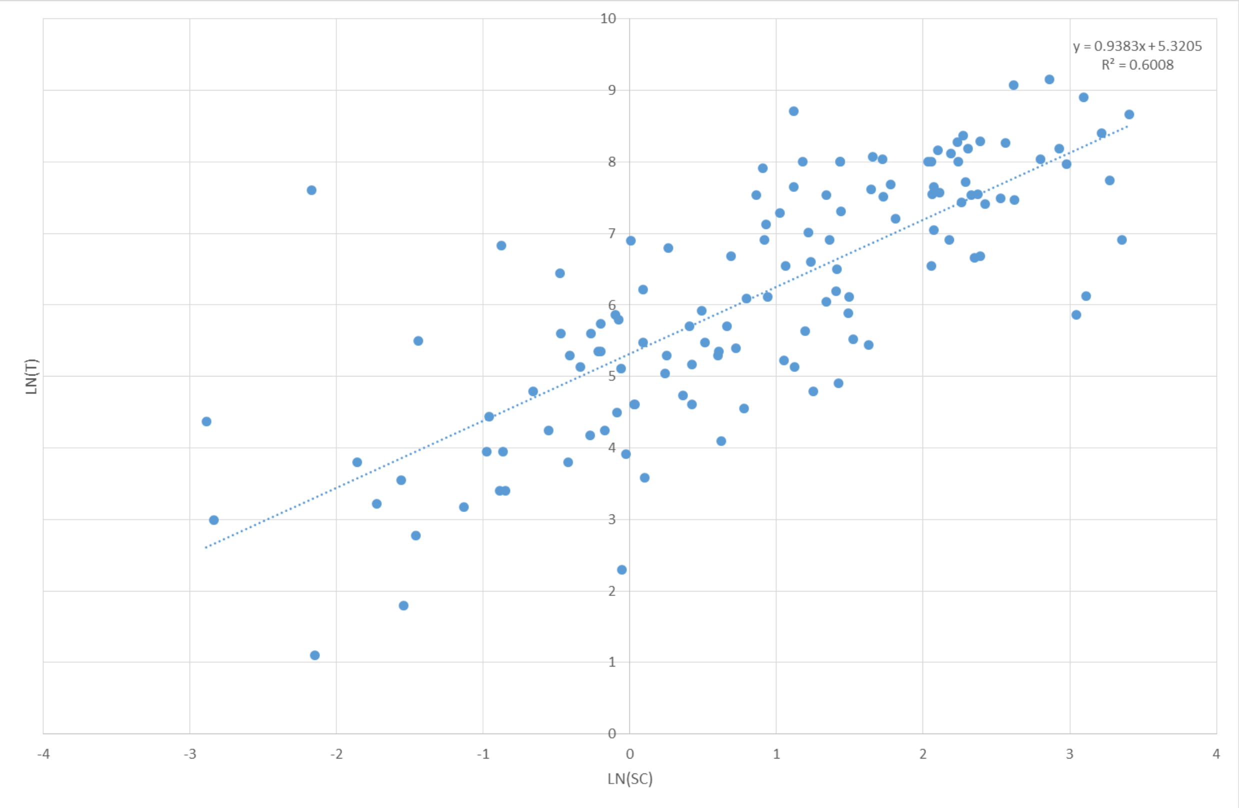


Figure 1 Log transformed specific capacity vs transmissivity – Waimakariri zone wells

I used the spherical model (standard model for variography) for all interpretation.

I interpreted hydraulic conductivity data in two dimensions under the assumption that the major permeability axis orientation does not change with depth. Although this assumption is unlikely to be correct, I did not have enough time to split the aquifer vertically and produce semi-variograms for different depth intervals. It is also uncertain whether there are enough data to do this, particularly for the deeper part of the aquifer system.

The sampling interval (spacing between locations at which we have estimates of hydraulic conductivity, K) is relatively large (even for the SC data), meaning that a high proportion of the mean sample population variance (e.g. 60%) is often found within the sampling interval. In addition to this, relatively large lag distances (e.g. 1000 m) are often required when interpreting variograms of SC for bulk scale anisotropy modelling. Very large lag distances (e.g. 3 km) are require to analyse the spatial variance of T data. I therefore assumed a nugget value at 10% of the mean variance, and generally used two structures to define the variograms model. This is shown in the semi-variogram plots later in this memo.

Analysis of the SC data for the whole domain did not show a clear major axis orientation, although two possible directions of continuity are apparent at 30-40° and 120-130° (Figure 3 a.). I therefore used a combination of judgment, knowledge of the depositional environment and visual analysis of aquifer properties (specific capacity and pumping test T values) to zonate the aquifer property data, to see if this would yield insights into spatial variance. I split the data into the following coarse zones (Figure 2):

1. Ashley
2. Halswell – Te Waihora
3. Inland Cust
4. Oxford – Eyre – Belfast
5. Selwyn

The elongated shape of the inland Cust zone would bias the interpreted major axis orientation so it was not appropriate to analyse data from this area. The Haswell – Te-Waihora zone is also elongated, so I included data from the eastern 5 km of the Selwyn zone in the Haswell – Te-Waihora zone analysis to remove this potential bias.

The zones were used to identify broad patterns in the data. I have recommended that the variogram models from these zones should be applied to a slightly different set of zones, as explained later in this memo.

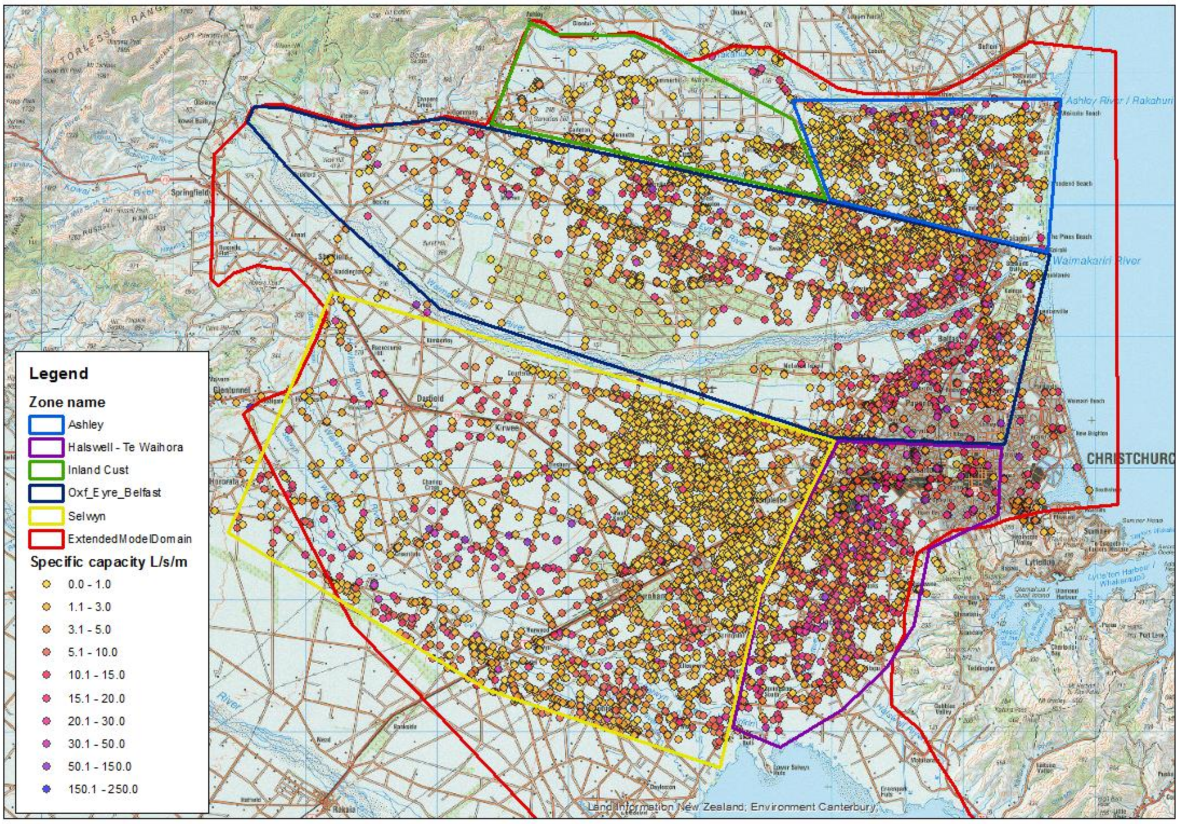


Figure 2 Zones used for to group data

Results

In summary, my analysis of spatial variance shows:

- No clear direction of continuity in the Ashley area
- A north-north east major axis in the Halswell/Te Waihora area (coastal confined aquifer system)
- An east-south east major axis orientation in the Oxford-Eyre-Belfast area

- A south east major axis orientation in the Selwyn area

I recommend that the model domain should be split into four zones for interpolation of model Kh values, as shown in Figure 5:

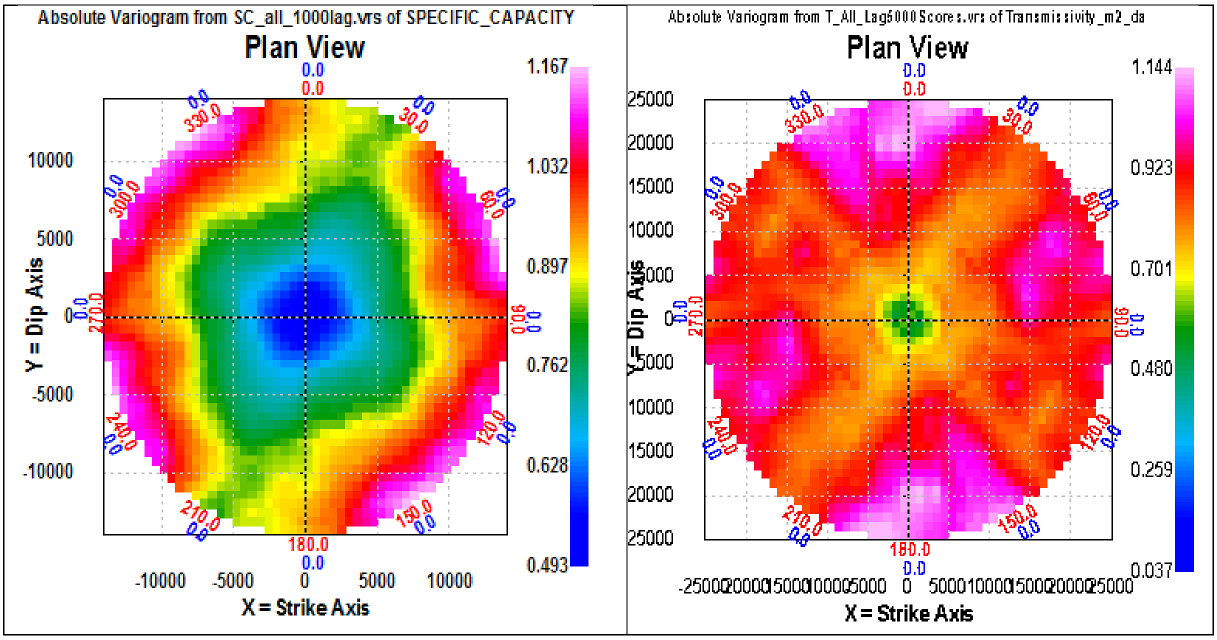
1. The Ashley River/Rakahuri area (use *SC Ashley* variogram model)
2. The Eyre zone inc. Yaldhurst (use SC *Oxf-Eyre-Belfast* variogram model)
3. Selwyn zone (use SC *Selwyn* variogram model)
4. The coastal confined aquifer system (use *SC Halswell/Te-Waihora* variogram model)

The generalised parameters summarised in Table 1 should be used for these models. A nugget of 0.1 (0.24 for non-normalised natural log transformed data) applies to all models.

Table 1 Summary of semi-variogram models

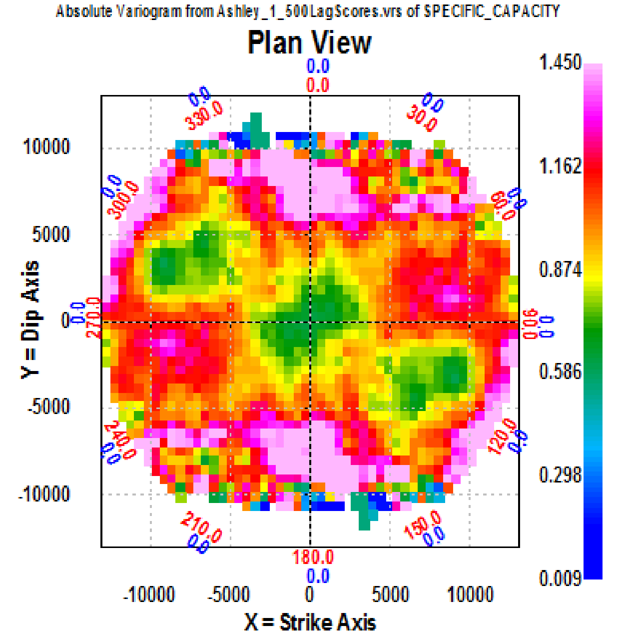
Data set	Axis	Azimuth (°)	Sill 1 (-)	Range 1 (m)	Sill 2 (-)	Range (m)
T (extended model domain)	Major	149	0.4	1,600	0.5	14,000
	Semi-major	49	0.38	1,600	0.52	11,400
SC Ashley	Major	100	0.5 (1.4)	160	0.4 (1.4)	5,200
	Semi-major	40	0.5 (1.4)	160	0.4 (1.4)	5,200
SC Halswell/Te-Waihora	Major	20	0.4 (0.84)	300	0.5 (0.93)	20,000
	Semi-major	110	0.32 (0.82)	300	0.58 (0.95)	5,300
SC Oxf-Eyre-Belfast	Major	110	0.47 (0.83)	300	0.43 (1.09)	13,000
	Semi-major	19	0.48 (0.85)	300	0.42 (0.88)	7,000
SC Selwyn	Major	140	0.51 (0.68)	300	0.39 (1.1)	17,000
	Semi-major	68	0.5 (0.68)	300	0.4 (1.1)	12,000

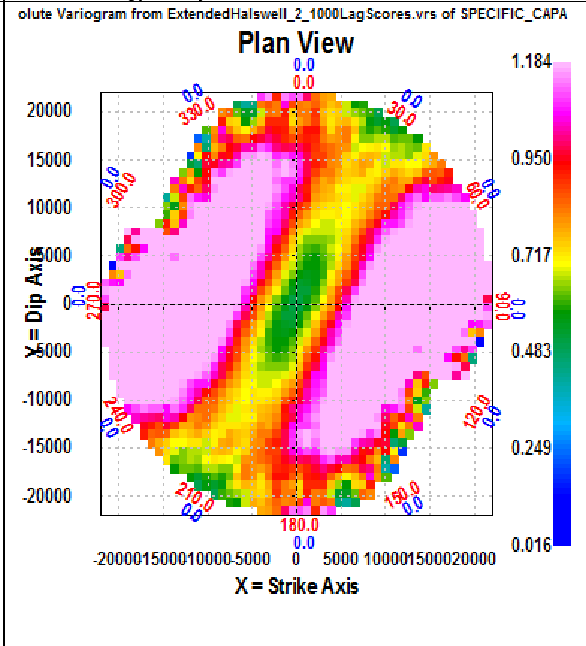
Figures in brackets denote sills for non-normailised natural log transformed specific capacity



a. Specific capacity – extended model domain (1 km lag). No clear orientation

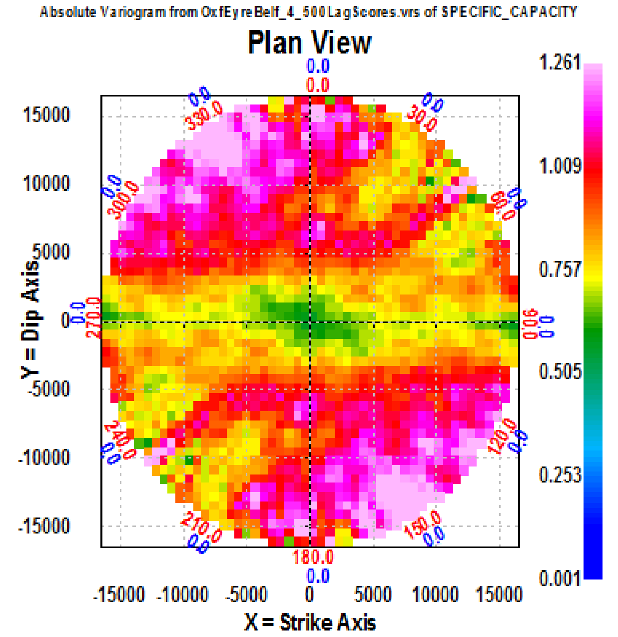
b. Transmissivity – extended model domain (5 km lag). Major axis azimuth 149°

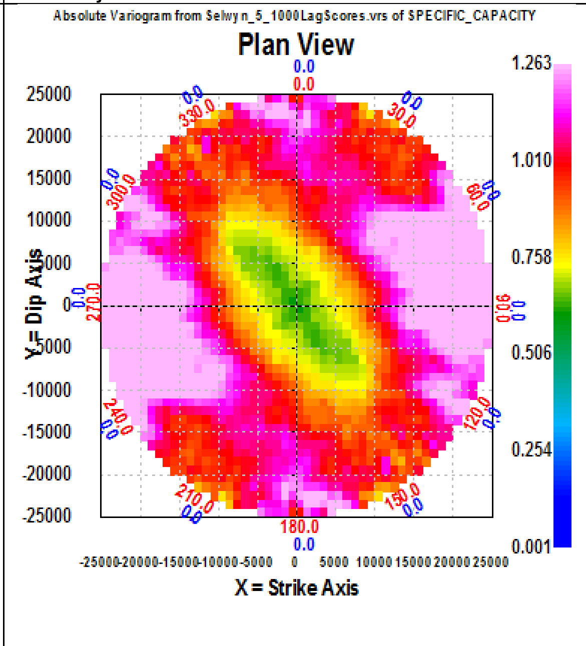




c. Ashley area – 500 m lag. No clear orientation

d. Halswell – Te Waihora – 1 km lag. Major axis azimuth 20°

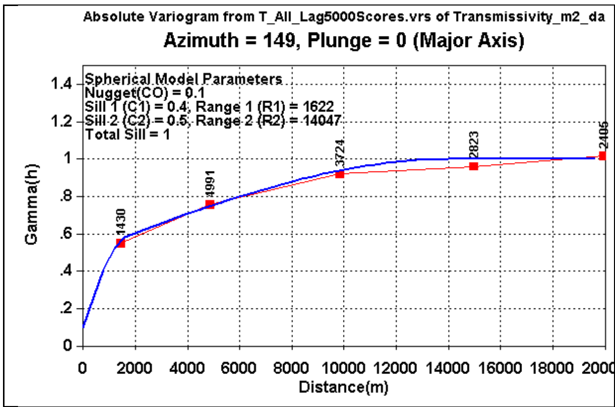




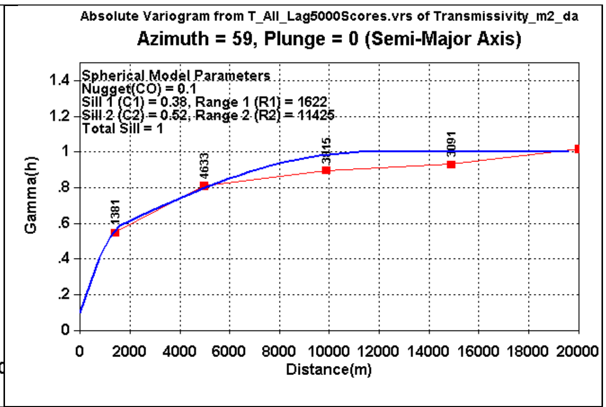
e. Oxford – Eyre – Belfast – 500 m lag. Major axis azimuth 110°

f. Selwyn – 1 km lag. Major axis azimuth 127°

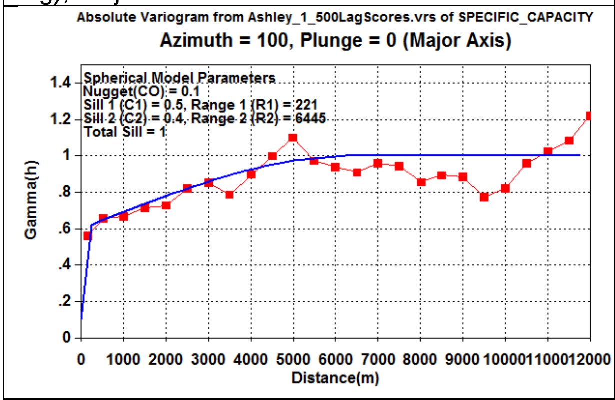
Figure 3 Variogram maps



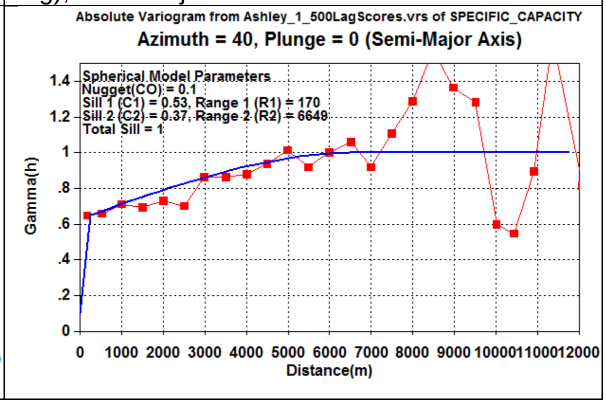
Transmissivity – extended model domain (5 km lag), major axis



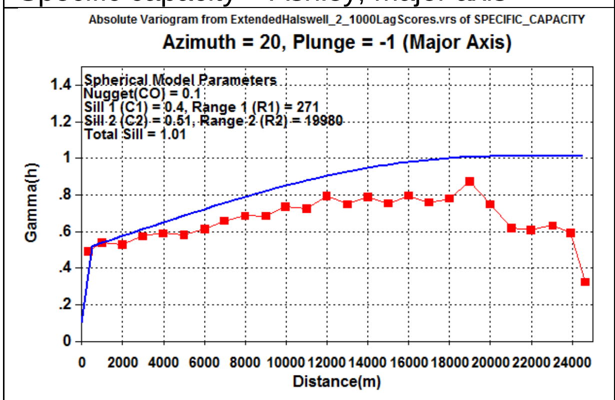
Transmissivity – extended model domain (5 km lag), semi-major axis



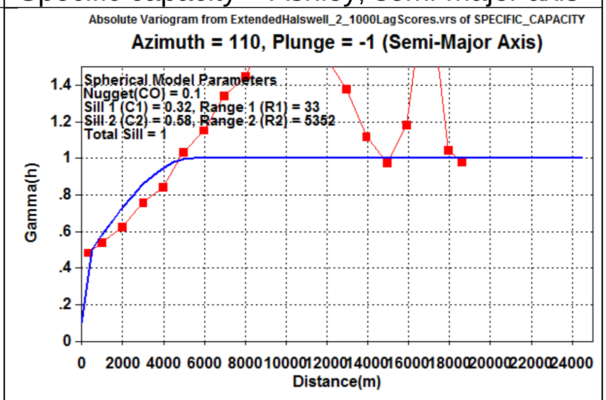
Specific capacity – Ashley, major axis



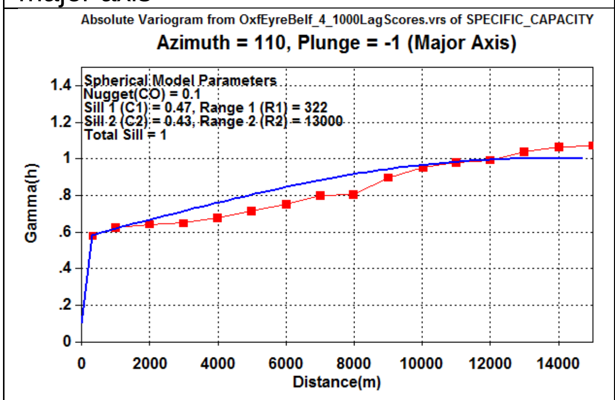
Specific capacity – Ashley, semi-major axis



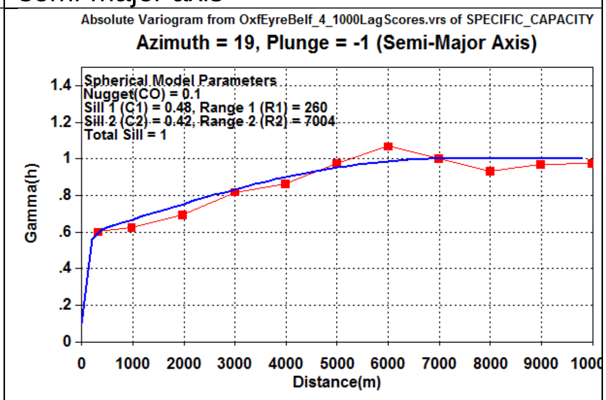
Specific capacity – Halswell/Te-Waihora, major axis



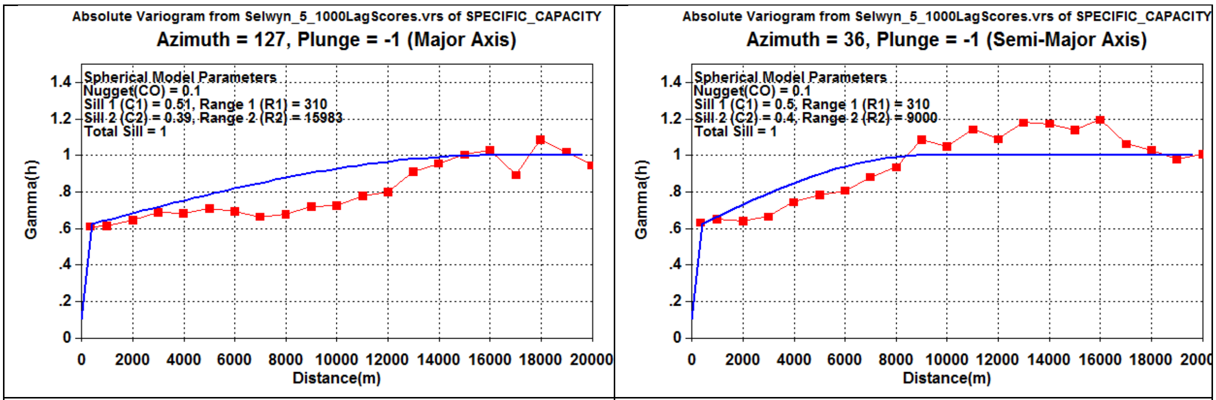
Specific capacity – Halswell/Te-Waihora, semi-major axis



Specific capacity – Oxford-Eyre-Belfast, major axis



Specific capacity – Oxford-Eyre-Belfast, semi-major axis



Specific capacity – Selwyn, major axis	Specific capacity – Selwyn, semi-major axis

Figure 4 Semi-variogram models

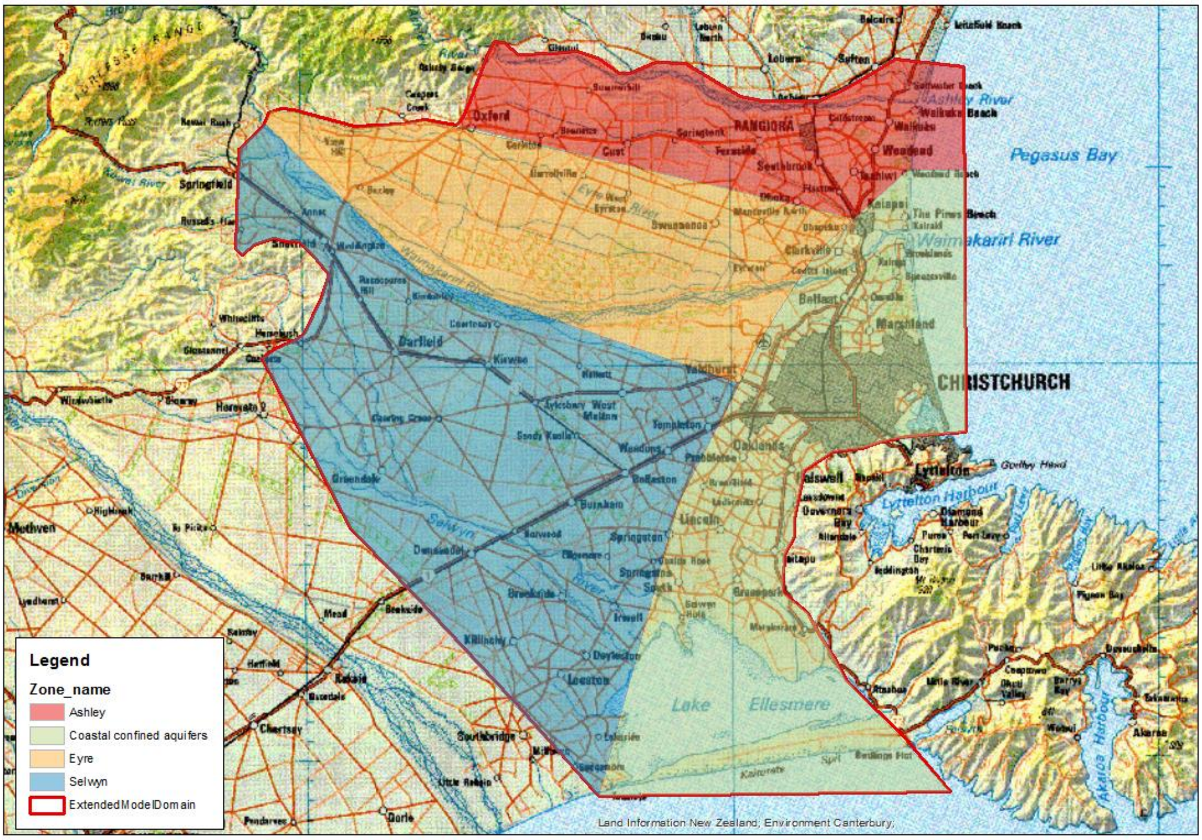


Figure 5 Proposed variogram model zones